2ND EDITION

HANDBOOK FOR PULP & PAPER TECHNOLOGISTS

G. A. Smook

[illegible] Wilde [illegible]

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Chapter 9

Processing of Pulps

Pulps are subjected to a wide range of processing steps, depending on their method of preparation (i.e., mechanical, semichemical, chemical virgin pulps; secondary fibers) and their end use. Screening, thickening and storage operations are necessary for virtually all pulp grades, while cleaning is usually required where appearance is important. Defibering is required for all semichemical and high-yield chemical grades. Deknotting is usually necessary in the production of clean bleachable chemical pulps. Blending operations are almost always desirable for achieving product uniformity, but are often omitted from the pulp processing scheme because of cost considerations. Pulp drying is required when pulp is stored for long periods (to prevent fungal or bacteriological activity) or shipped over considerable distances (to reduce freight costs).

A schematic flowsheet for a kraft dissolving pulp mill is shown in Figure 9-1 (next page) to illustrate a representative sequence of processing steps.

9.1 DEFIBERING

All high-yield chemical and semichemical pulps must be defiberized by mechanical means following the cooking step. At the highest yields (i.e., 80–90%), the operation is akin to chip refining (see Section 5.3), requiring high levels of applied energy to separate the fibers. In the lower-yield range (50–60%), considerably less energy is required. Defiberization of chemical pulps should be considered apart from pulp refining which is carried out in the paper mill; however, it must be recognized that the method and degree of defiberization will have an effect on later refining requirements.

Investigative work has shown that energy requirements are generally lower when the defibering can be carried out in the presence of hot residual liquor (i.e., "hot stock refining"). Since washing the chips is difficult anyway, it is almost universal practice to defiber directly from the blow tank (1). Some systems utilize a second stage of refining following washing of the pulp.

Disc refiners are commonly used for defibering. A popular configuration utilizes one double-sided rotating disc between two stationary discs. Feed is into the eye of the refiner. The stock then flows radially outward between each pair of facing discs, is collected in an annular casing, and then flows under pressure out a discharge port.

Refer to Sections 20.4 and 20.5 for specific applications of defibering.

9.2 DEKNOTTING

In a low-yield (i.e., bleachable grade) chemical pulping operation, knots are generally defined as the fraction of pulp that is retained on a 3/8" perforated plate. These rejects are most often composed of irregular shaped reaction wood pieces or overthick chips, but sometimes normal-size uncooked chips are present. Knots are removed from the pulp prior to washing, and are either discarded as waste or returned to the digester infeed.

As a control procedure, it is good practice to routinely monitor the level of knots (as % on pulp) and qualitatively characterize the reject material. A high percentage of knotter rejects, especially when showing a high proportion of uncooked chips, usually indicates poor cooking uniformity. Figure 9-2 shows some mill data on knot levels measured before and after the implementation of a process modification which was designed to improve liquor circulation.

Two types of knotters are in use. The older, vibrating screen knotters do an efficient job of knot separation, but the open-type design generates foam and liquor spatter, and needs operator attention. Foam in the stock impairs the efficiency of the subsequent washing operation and can cause other problems. The vibratory knotter is rapidly being superseded by the totally enclosed pressure screen knotter.

The pressure screen knotter (e.g., Figure 9-3) consists of a totally enclosed cylindrical, perforated screen through which accepted stock flows. A rotating foil produces a series of pressure and vacuum pulses to keep the perforations clean. Knots are retained on the entrance side of the screen and are continuously discharged, along with some good fiber. The main drawback of the pressure knotter is the requirement for secondary screening of the reject stream to return good fiber back to the system.

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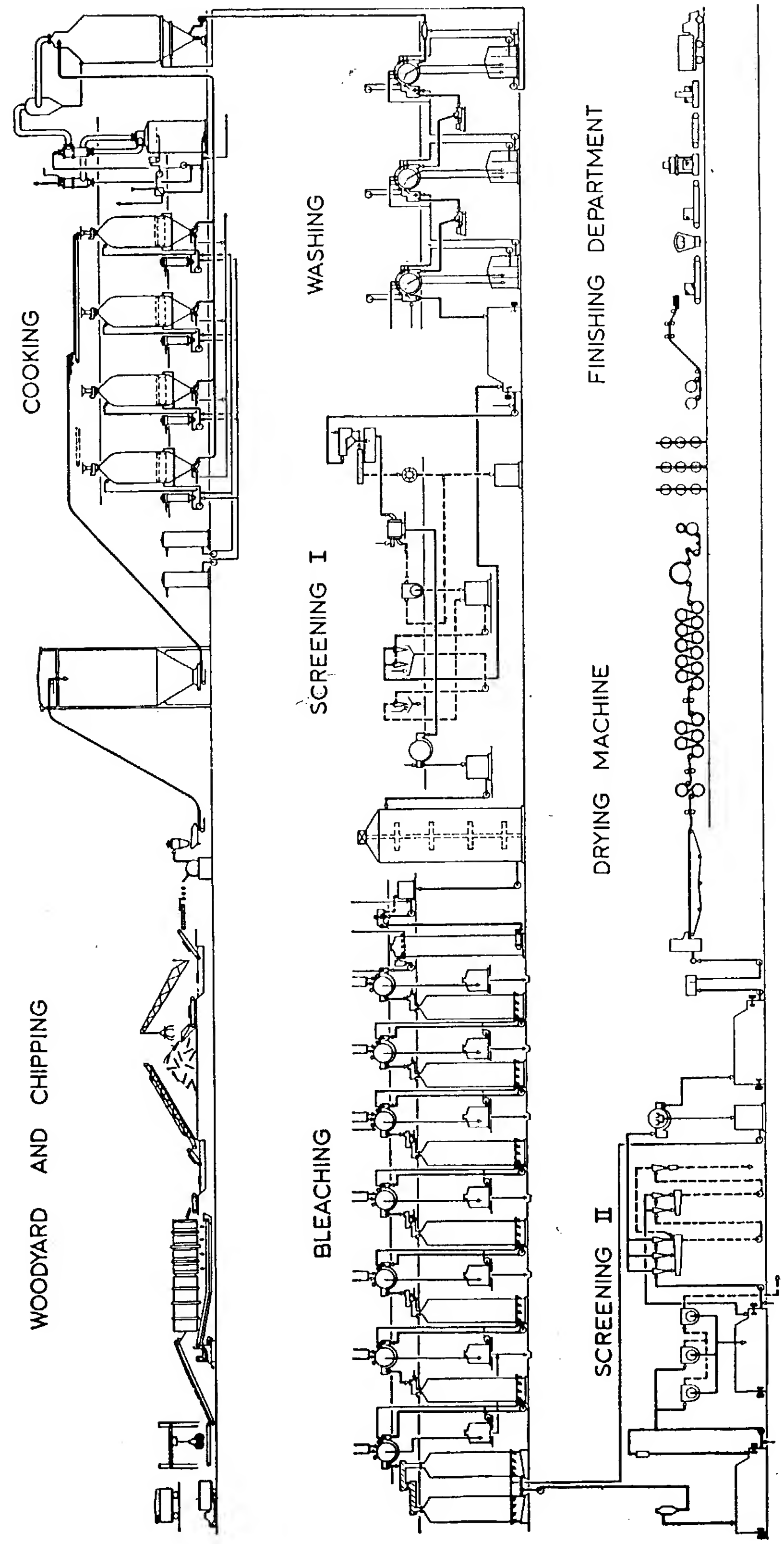

FIGURE 9-1. Schematic flowsheet for kraft dissolving mill.

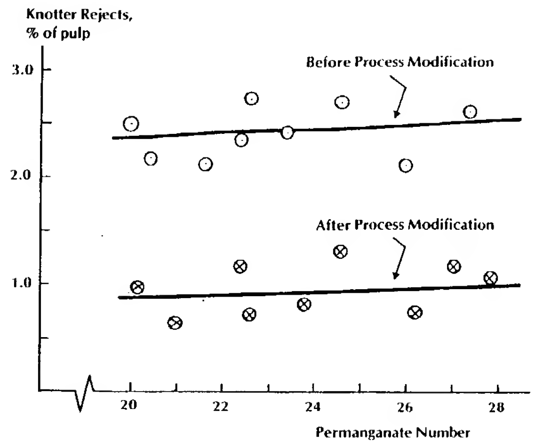

FIGURE 9-2. Knotter reject level vs permanganate number during two periods of operation.

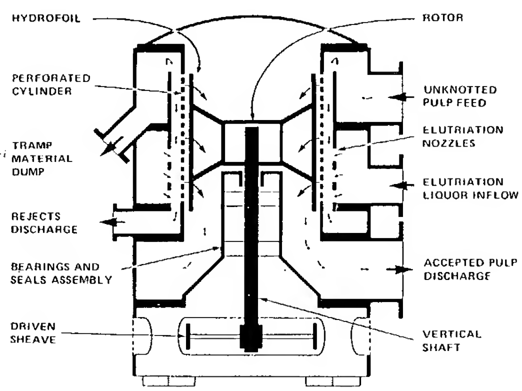

FIGURE 9-3. Cross-section schematic of pressure knotter (Impco/Ingersoll Rand).

9.3 BROWN STOCK WASHING (REFERENCES 2, 3, AND 4)

The cooked pulp from the digesters must be washed, with the objective to:

- remove residual liquor that would contaminate the pulp during subsequent processing steps.
- recover the maximum amount of spent chemicals with minimum dilution.

For many decades, the standard method of washing was to employ a series of rotary vacuum washers operating in a countercurrent flow sequence. Today, a number of alternative methods are available to challenge the predominant position of the rotary vacuum washer, the most prominent being:

- pressure and atmospheric diffusion washers
- rotary pressure washer
- horizontal belt washer
- dilution/extraction equipment.

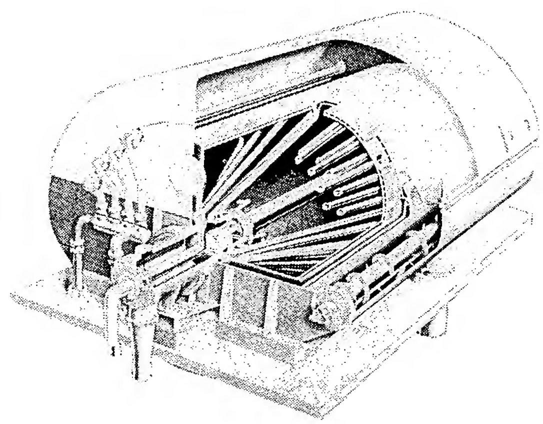

FIGURE 9-4. Internal structure of single-stage vacuum washer (Beloit Rauma).

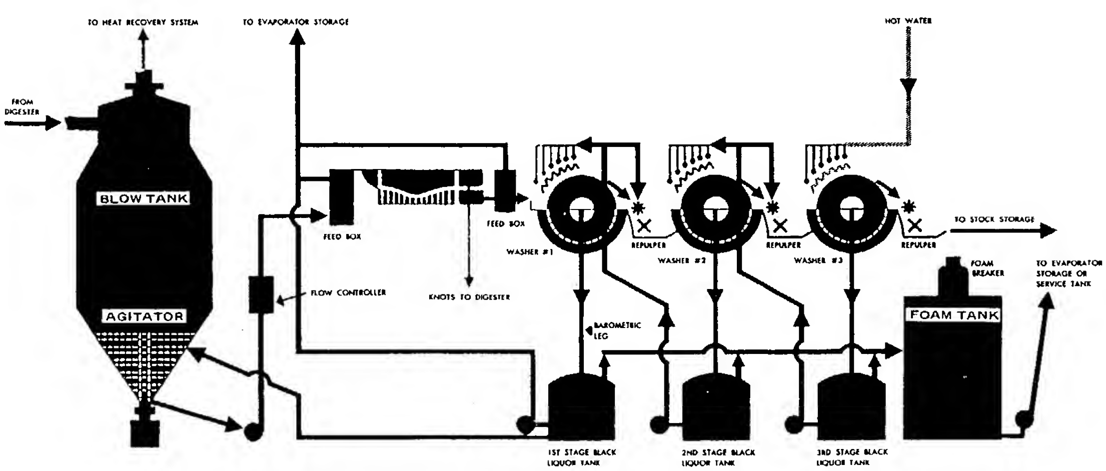

FIGURE 9-5. Typical flow sequence for countercurrent rotary brown stock washers.

Rotary Vacuum Washer

The main element of a vacuum washer is a cloth-covered cylinder that rotates in a vat containing the pulp slurry. By means of internal valving and a sealed dropleg, vacuum is applied as the rotating drum enters the stock. A thick layer of pulp builds up and adheres to the wire face as it emerges from the vat. Wash water is applied to displace the black liquor in the sheet as the drum continues to rotate. Finally, the vacuum is cut off and the washed pulp is removed from the mold. A representative design of vacuum washer is illustrated in Figure 9-4. A typical countercurrent arrangement of these washers is shown in Figures 9-5 and 9-6. (Refer also to Section 9.6.)

Although a displacement mechanism is used (as illustrated in Figure 9-7), the average efficiency of displacement for a single stage rarely exceeds 80%, due to a number of factors. Consequently, three of four stages are required to attain an overall satisfactory removal of 99% of the "washable" liquor solids. A small portion of the soda is chemically bound to the kraft pulp fibers and cannot be recovered by conventional washing techniques. A listing of the factors affecting displacement efficiency is given in Table 9-1. Reference 2 provides a good discussion of the more important variables. Perhaps the key variables are specific loading, dilution factor, and the amount of air in the stock.

Specific loading is commonly measured in oven-dry tons per day of pulp per square foot of cylinder surface (BDTPD/sq ft). Typical loading values are in

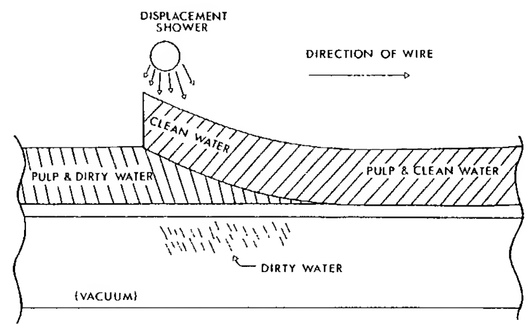

Figure 9-7. Illustrating displacement principle of rotary vacuum washer.

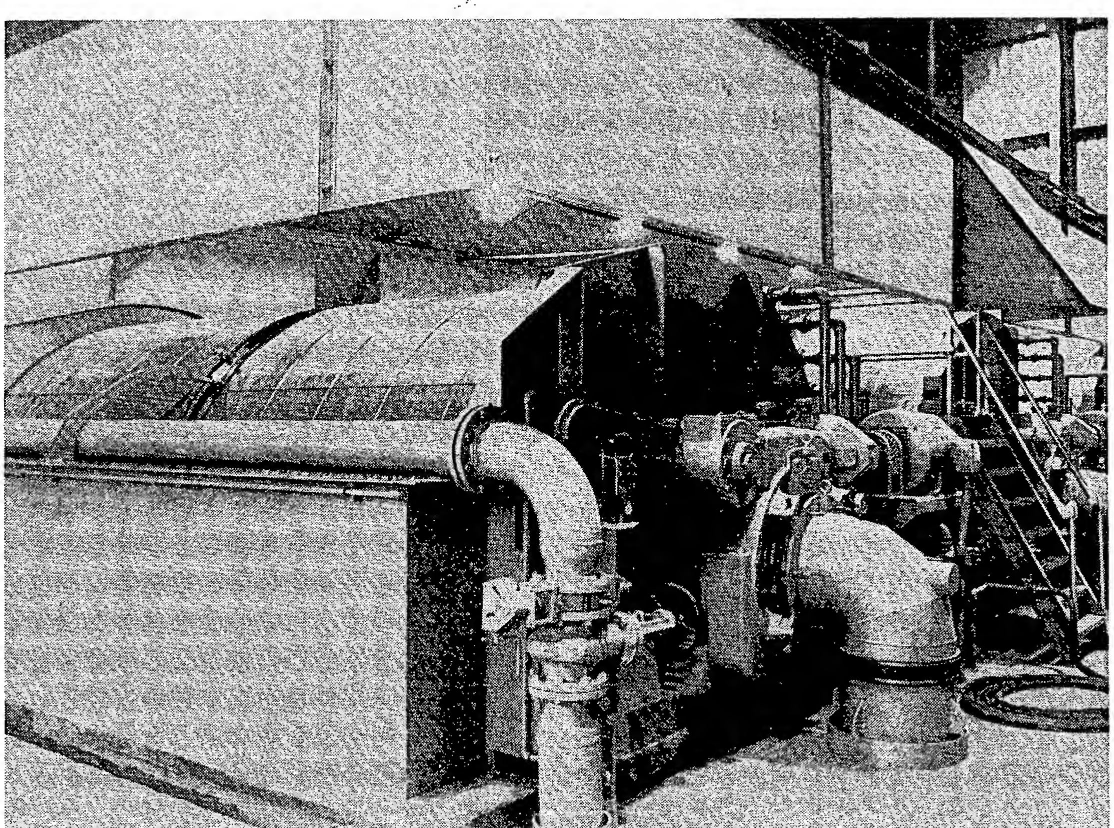

Figure 9-6. Brown stock vacuum rotary washers (Impco/Ingersoll Rand).

TABLE 9-1. Factors affecting brown stock washing displacement efficiency.

Fiber Characteristics
- pulping process
- stock hardness
- stock freeness
- species

Shower Characteristics
- temperature
- distribution
- method of application

Sheet Formation/Thickness
- specific loading
- vat consistency
- vat rotational speed

Operating Factors
- dilution factor
- stock temperature
- air in stock (foam)
- liquid solids level
- fabric mesh characteristics
- fabric fouling

the 0.6 to 0.8 range; overloaded conditions (common in mills with expanded production) contribute to poor washing.

Dilution factor is a measurement of the wash water applied in excess of that required for total displacement, expressed as pounds of water per pound oven-dry pulp. Generally, a higher dilution provides better washing. But the dilution factor is also a direct measure of the water being added to the liquor system. Therefore, the washing benefit achieved at higher dilution factor must be balanced against the higher evaporation loading.

In any vacuum washing operation, a certain amount of air is continuously pulled through the pulp sheet, entrained with the liquor, and carried down the dropleg into the seal tank. It is important that this air has a chance to escape before the liquor is reused to minimize foaming problems. This objective is usually accomplished by installing large seal tanks, the diameter of which may be double the height; the large surface area allows air to escape and foam bubbles to break. In some situations, mechanical foam breakers are also used.

An important design consideration that affects washing efficiency and foam generation is the method of wash liquor application. The liquid should be applied uniformly at low velocity to avoid channelling and foaming. High-pressure jets or nozzles are unsatisfactory; low-pressure nozzles usually provide uneven application and quickly become plugged with deposits. The ideal method of application is with a weir-type shower, which usually consists of a pressurized pipe submerged in an open trough. The wash liquor is distributed into the trough through a series of submerged holes, and is then transferred without turbulence over a bent plate onto the pulp sheet. Surprisingly, weir-type showers are used on only a small portion of rotary washers.

The displacement washing effect is readily calculated from the ratio of the actual reduction in liquor solids content (compared) to the maximum possible reduction. For a single stage:

$$\text{Displacement Ratio (DR)} = \frac{C_V - C_S}{C_V - C_W}$$

where:
C_V = Vat liquor solids concentration
C_W = Wash liquor solids concentration
C_S = Solids concentration in sheet leaving washer

It can be noted that, when water is used as the wash liquor, C_W equals zero.

However, the removal of dissolved liquor solids at the brown stock washers is accomplished both by displacement and thickening. The thickening effect is calculated:

$$\text{Thickening Factor (TF)} = \frac{W_{(in)} - W_{(out)}}{W_{(in)}}$$

where:
$W_{(in)}$ = lbs of liquor per lb pulp (stock entering)
$W_{(out)}$ = lbs of liquor per lb pulp (stock leaving)

Also note:

$$W = \frac{100 - \text{Consistency}}{\text{Consistency}}$$

Thus, the overall efficiency of dissolved solids removal is calculated:

$$\%\ \text{Efficiency} = [\text{TF} + (1 - \text{TF})\ \text{DR}]\ 100$$

On a routine basis, the efficiency of washing is monitored by the amount of soda (or equivalent saltcake) remaining with the washed pulp. A washing efficiency of 99% is usually equivalent to a carryover of about 15 to 20 lbs/BDT of washable equivalent saltcake. (If total soda losses are to be calculated, the chemically-bound soda must also be considered.)

Diffusion Washing

Diffusion washing was first applied to the chip mass in the bottom of the Kamyr continuous digester (see Section 8.3). Later, the principle was adapted and applied by Kamyr to the washing of pulp; the first commercial atmospheric diffusion washers were installed in 1965; the first commercial pressure diffusion washers (independent of the digester) were installed in 1979. Diffusion washing is characterized by a relatively long period of contact between the cooked chips or pulp and the moving wash liquor, which allows time for the liquor solids to diffuse or leach from the fiber structure. These processes take place in a submerged environment, which excludes the possibility of air entrainment and foaming.

An ideal situation for diffusion washing (or "high heat washing", Kamyr's descriptive term) exists at the bottom of the Kamyr chip digester (see Figure 9-8). Here, retention times of up to four hours are possible with wash zone temperatures of 130 – 140°C and truly countercurrent flows. The level of washing efficiency that can be achieved is a function of the dilution factor and the retention time as illustrated in Figure 9-9. In practice, the downward flow of the chip mass in the digester may be impeded at higher dilution factors, especially when the digester is operating near maximum capacity. The limiting dilution factor must be determined on an individual basis.

A different situation exists in the bottom of the Kamyr sawdust digester (Figure 9-10). A true countercurrent flow cannot be used because of resistance within the closely packed pulp mass. The method used is to add wash liquor at the periphery and extract displaced liquor through a central rotating screen; the relatively fast movement of the screen prevents plugging. Typical wash zone retention is limited to about 20 minutes.

An atmospheric diffusion washer for pulp is illustrated in Figures 9-11 and 9-12. Single and

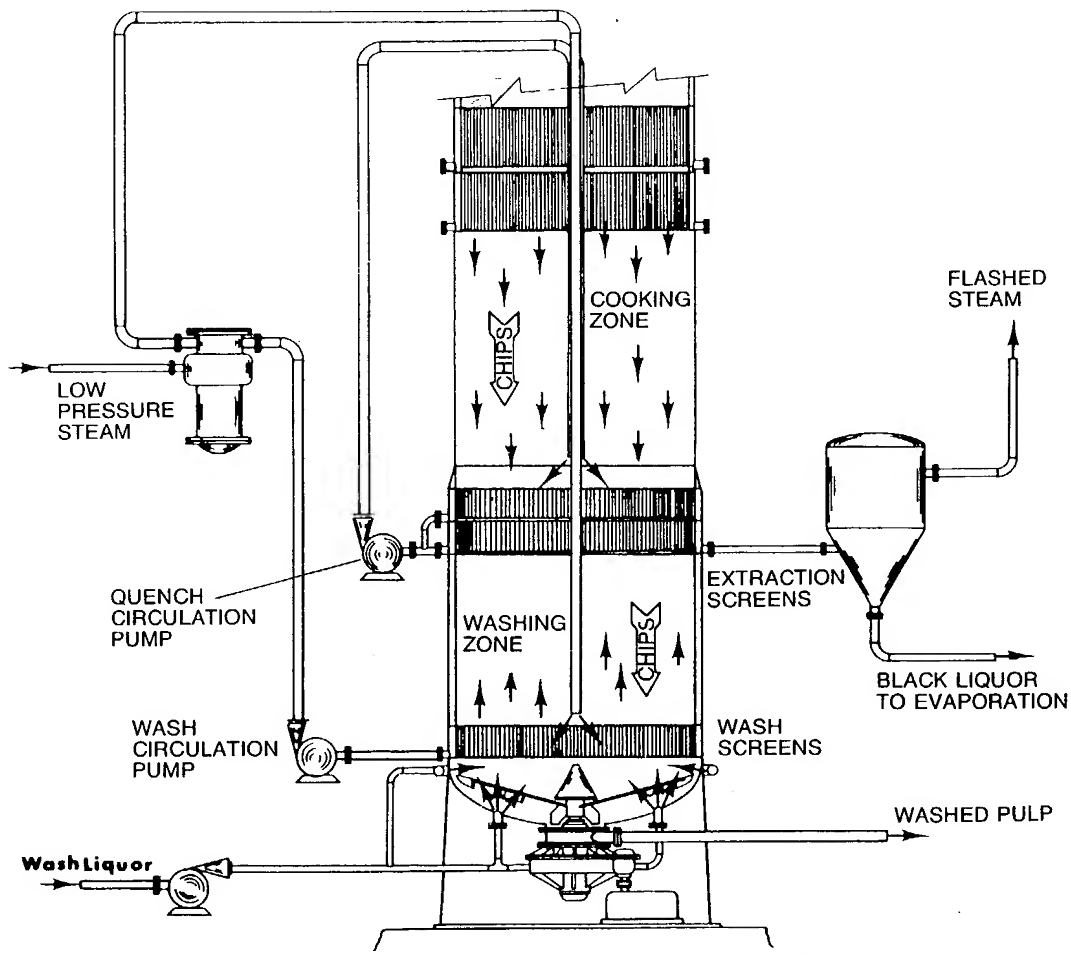

FIGURE 9-8. Internal washing zone in a typical Kamyr chip digester.

multistage units are available; Figure 9-13 depicts a total of three stages with thickener. The units consist of a series of double-sided, concentric screens with distribution nozzles between each screen. The entire screen assembly is mounted on a set of hydraulic cylinders and moves up at the same rate as the pulp. At the top of the stroke, the screen assembly is moved rapidly downward, thus providing a wiping action to keep the screen surface clean. Wash liquor is added through the nozzles, and the displaced liquor is extracted through the screens. In a multistage arrangement, the pulp moves upward; the extracted liquor from an upper unit is used as wash liquor for the next stage below. Typically, the

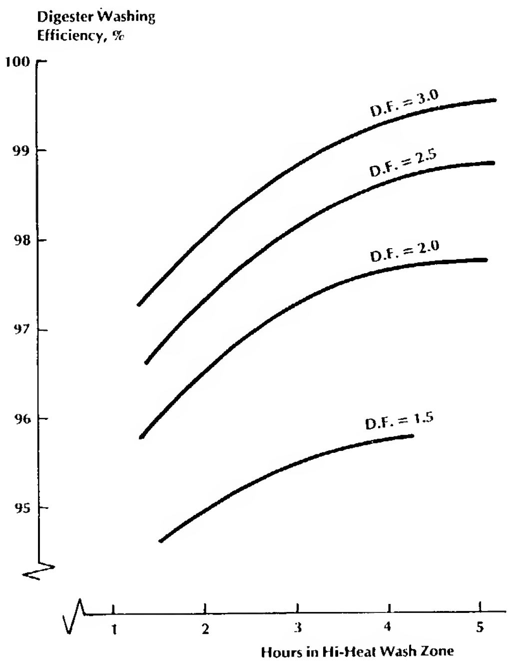

FIGURE 9-9. Effect of wash time and dilution factor on high-heat digester diffusion washing efficiency.

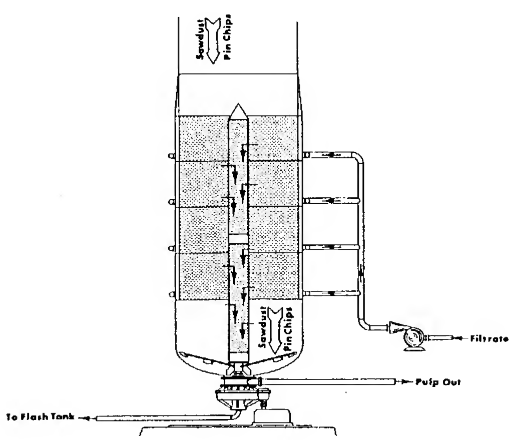

FIGURE 9-10. Internal washing zone in a Kamyr sawdust digester.

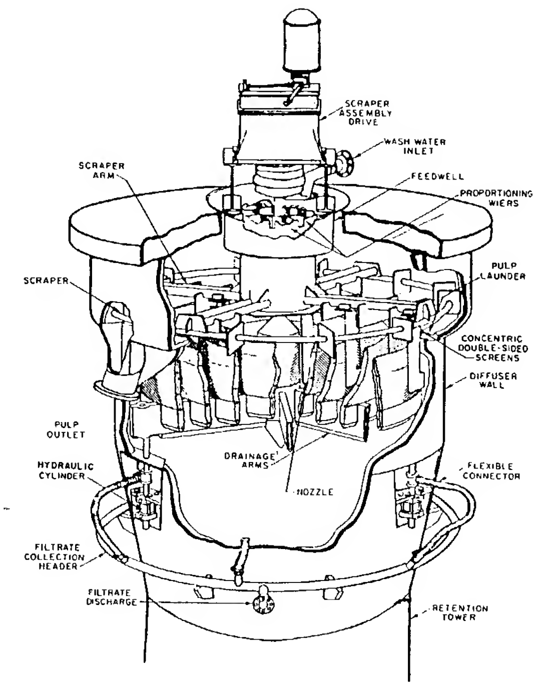

FIGURE 9-11. Cut-away drawing shows how the Kamyr diffusion washer is designed and how it works.

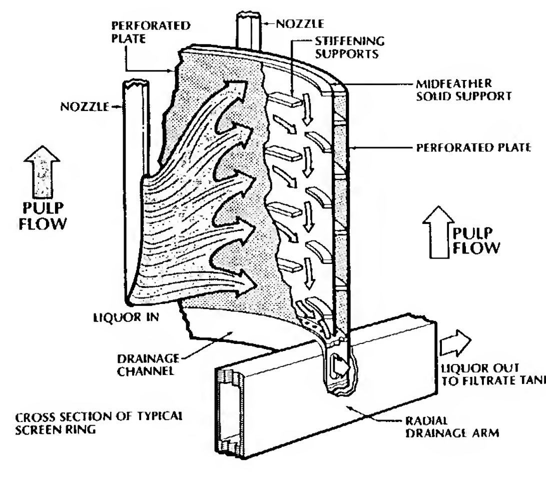

FIGURE 9-12. Schematic of Kamyr diffusion washer screen assembly. The washing medium is introduced through rotating distribution nozzles. The displaced liquor is collected through the screens and flows into the drainage arms.

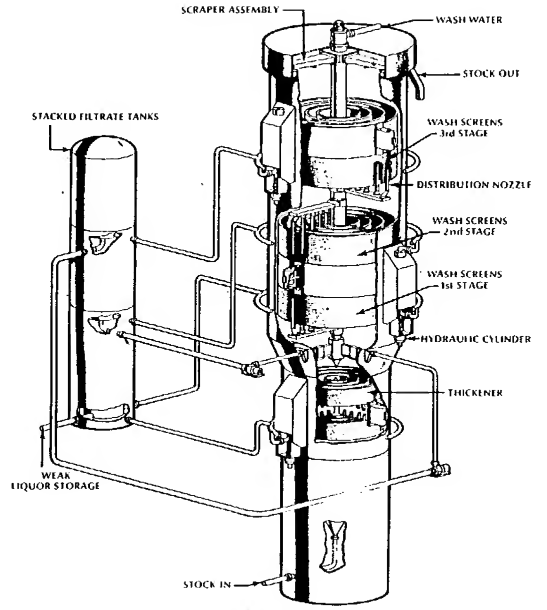

Figure 9-13. Three-stage diffusion washer with thickener (Kamyr).

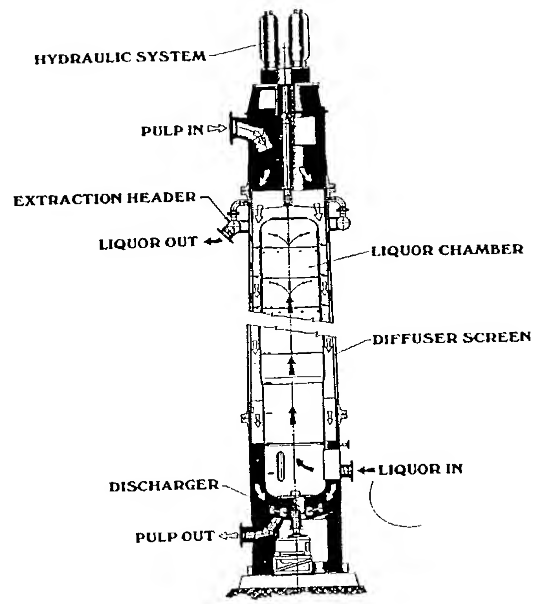

Figure 9-14. Kamyr pressure diffusion washer.

retention time per stage is 8 to 10 minutes.

The Kamyr pressure diffusion washer (Figure 9-14) is similar in operation to the Kamyr sawdust digester internal washer, and was designed principally for placement in series with the Kamyr digester internal washer. The pulp at blow-line consistency is introduced at the top of the vessel and is caused to flow downward through an annulus formed by a slightly tapered cylindrical screen and a central liquor chamber. The wash liquor is injected from the central chamber and is forced to flow to the screen, where it is extracted. As in other designs, the screen is moved periodically in the direction opposing the flow of pulp to wipe the pulp from the screen and prevent plugging.

Pressure Washers

Rotary pressure washers (Figures 9-15 and 9-16) are similar in operation to rotary vacuum washers, but appear to offer some significant advantages. The pulp mat is formed on the surface of the cylinder and dewatered with the aid of pressure applied inside the washer hood (i.e., outside the cylinder), as opposed to vacuum inside the cylinder. Because the driving force for mat formation, dewatering and wash liquor displacement is outside the cylinder, the interior of the washer drum can be utilized for a more sophisticated liquor collection system; therefore, a single washer can be operated with two or three displacement stages. The higher pressure also allows higher-temperature wash liquor to be used and

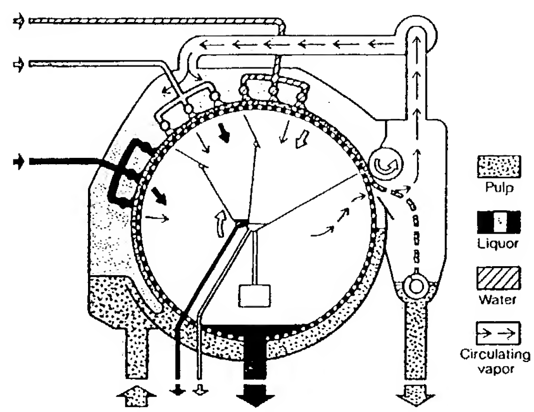

Figure 9-15. Basic principle and design of pressure washer (Beloit Rauma).

greatly reduces foaming. The closed vapor circulation system facilitates collection and treatment of odorous vapors.

Horizontal Belt Washer

The horizontal belt washer (Figure 9-17) resembles the fourdrinier section of a paper machine. The pulp suspension is distributed from a headbox onto a traveling filter belt (e.g., plastic screen or steel band), and formed into a mat. Wash liquor is applied to the top side of the mat while displaced filtrate is removed from the underside of the belt by suction

boxes. The washer is operated in a countercurrent mode, with the filtrate from one section being returned as wash liquor to the previous section, and ultimately as dilution for the headbox furnish. In common with the vacuum washer, displacement is the principal washing mechanism, but no mixing and reforming of the pulp mat is required between stages. A total of five displacement stages are easily accommodated along the belt.

Dilution/Extraction Equipment

Dilution and extraction is the oldest method of pulp washing. It consists simply of diluting a pulp slurry with weaker liquor, and subsequent thickening. The efficiency of this type of system is dependent upon the ratio of the discharge to the incoming consistency and the amount of dilution water added to the system. Older systems were inefficient due to limitations in thickening, but modern extraction presses, some having a displacement washing capability, are capable of discharge consistencies of 30 - 40%, and multi-stage systems can be competitive with vacuum washer systems.

Figures 9-18, 9-19 and 9-20 depict three of the

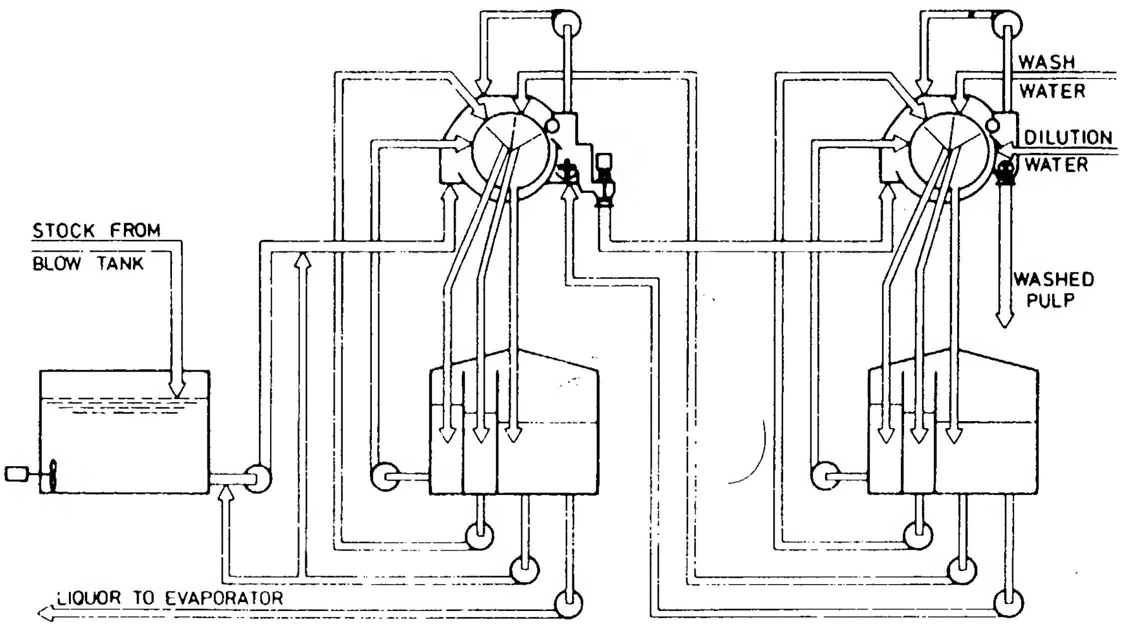

FIGURE 9-16. Flowsheet comprising two three-stage pressure washers (Beloit Rauma).

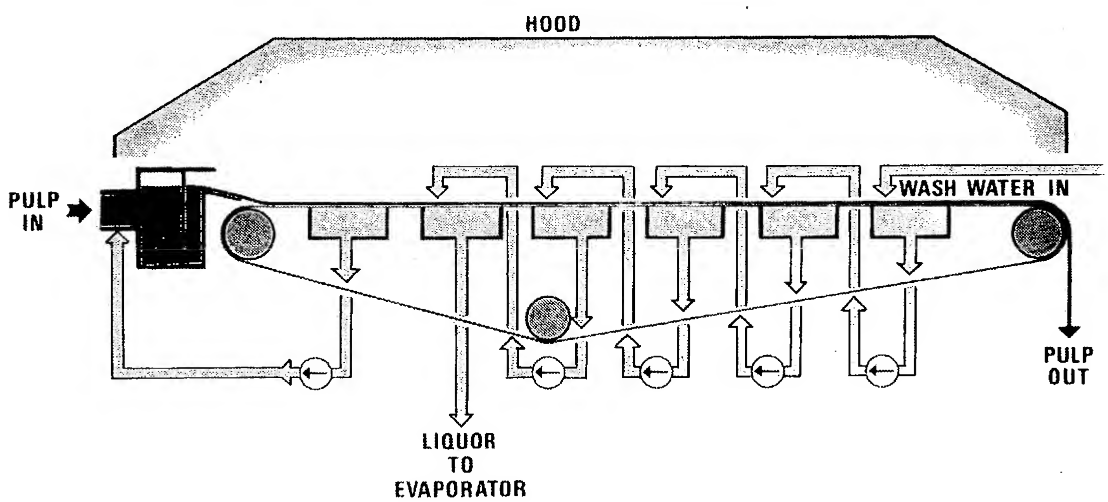

FIGURE 9-17. Schematic of horizontal belt washer system (Black Clawson Co.)

available designs for dilution/extraction equipment. This class of equipment is especially applicable for pulps that are difficult to permeate, i.e., where a displacement-type washer would not be an appropriate choice.

Norden's Method

In view of the recent proliferation of new washing methods and the possibility of connecting different types of washing equipment in series, it would be desirable to assign an efficiency number to equipment which is independent of dilution factor. Norden's method (5) has been widely applied toward this objective. It assumes that a washing stage can be likened to a number of countercurrent mixing stages connected in series. In an individual stage, the pulp and associated solids-containing liquor (from the previous stage) are mixed with lower-solids wash liquor (from the next stage); the stock is then re-thickened to the original consistency and the separated stock and liquor are passed countercurrently to their respective next stages.

The Norden efficiency factor is defined as the number of mixing stages which will give the same results as the washing equipment under consideration, when operated at the same wash liquor ratio. Table 9-2 provides a ranking of equipment utilizing a slightly modified Norden efficiency factor. A range of values is the natural consequence of different fiber types and varying operating conditions. The total Norden efficiency for a system may be found simply by adding the factors for the various components. Given the system Norden efficiency and the dilution factor, the anticipated washing efficiency of the system can be found from Figure 9-21 (6).

9.4 SCREENING

In most pulp and paper processes, some type of stock screening operation is required to remove oversized, troublesome and unwanted particles from good papermaking fibers. The major types of stock screens are vibratory, gravity centrifugal, and pressure (centrifugal or centripetal). They all depend on some form of perforated barrier to pass acceptable

TABLE 9-2. Modified Norden efficiency factors for various types of washing equipment.

	Efficiency Factor
Vacuum drum washer	2.5 – 4
Single-stage diffuser	3 – 5
Kamyr sawdust digester wash zone	5 – 9
Kamyr chip digester:	
1½ h in hi-heat zone	4 – 6
3 h in hi-heat zone	7 – 11

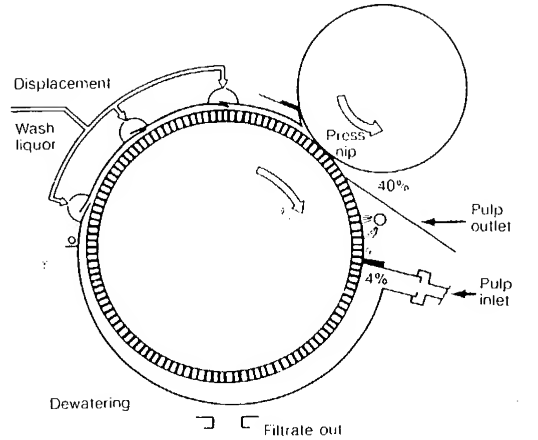

FIGURE 9-18. Operating principle of wash press (KMW).

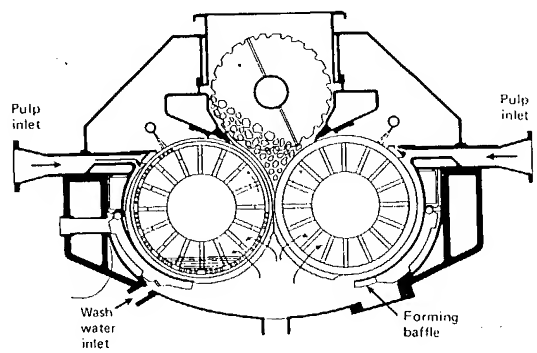

FIGURE 9-19. Extraction press unit (Impco/Ingersoll Rand).

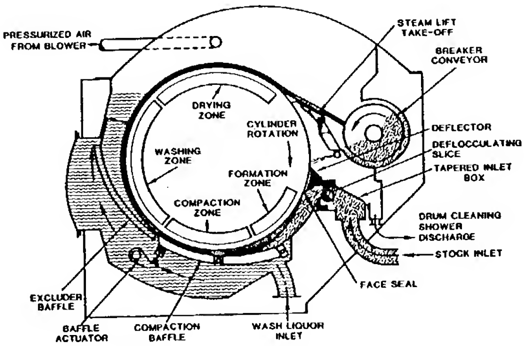

FIGURE 9-20. Schematic cross-section of compaction baffle filter (Impco/Ingersoll Rand).

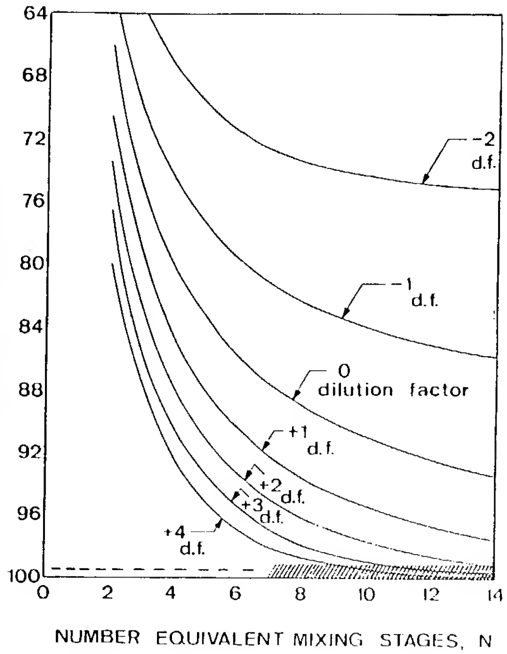

FIGURE 9-21. System washing efficiencies at different dilution factors and modified Norden numbers. Note that applicability is not valid above 99% efficiency because of diffusion/sorption effects.

fiber and reject the unwanted material. In most instances, it is the size of the perforations (usually holes or slots) that determine the minimum size of debris that will be removed.

All screens must be equipped with some type of mechanism to continuously or intermittently clean the openings in the perforated barrier. Otherwise, the screen plate would rapidly plug up. Methods of cleaning employed on current commercial screens include shaking and vibration, hydraulic sweeping action, back-flushing or, most common, pulsing the flow through the openings with various moving foils, paddles and bumps.

The typical screen is a relatively simple machine to operate. The most important consideration for stable, efficient operation is to maintain flow and consistency near optimum levels. When problems occur, they are usually due to clear overloading or underloading; but a relatively wide range of operation is possible between these extremes.

Vibratory Screens

Vibratory flat screens at one time were practically the only type used in pulp and paper mills. This screen is capable of efficient separation and concentration of reject material. However, its many disadvantages (e.g., open construction, foam problems, high maintenance, labor intensity, large floor area requirement) have rendered it obsolete for all but specialized applications. It is still the best tailings screen (for concentration of rejects). The same design concept is embodied in the laboratory flat screen, which is used for measuring debris levels on stock samples.

The rotary vibratory screen is more compact than the flat screen and requires less operator attention. But, the high maintenance cost has also rendered this design obsolete for most applications.

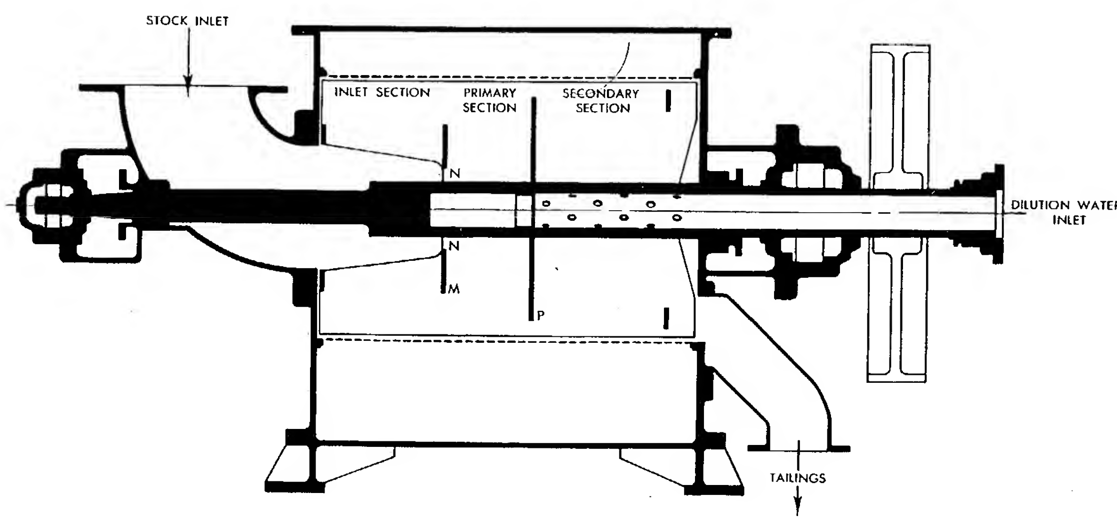

FIGURE 9-22. Example of gravity centrifugal screen (S.W. Hooper Corp.).

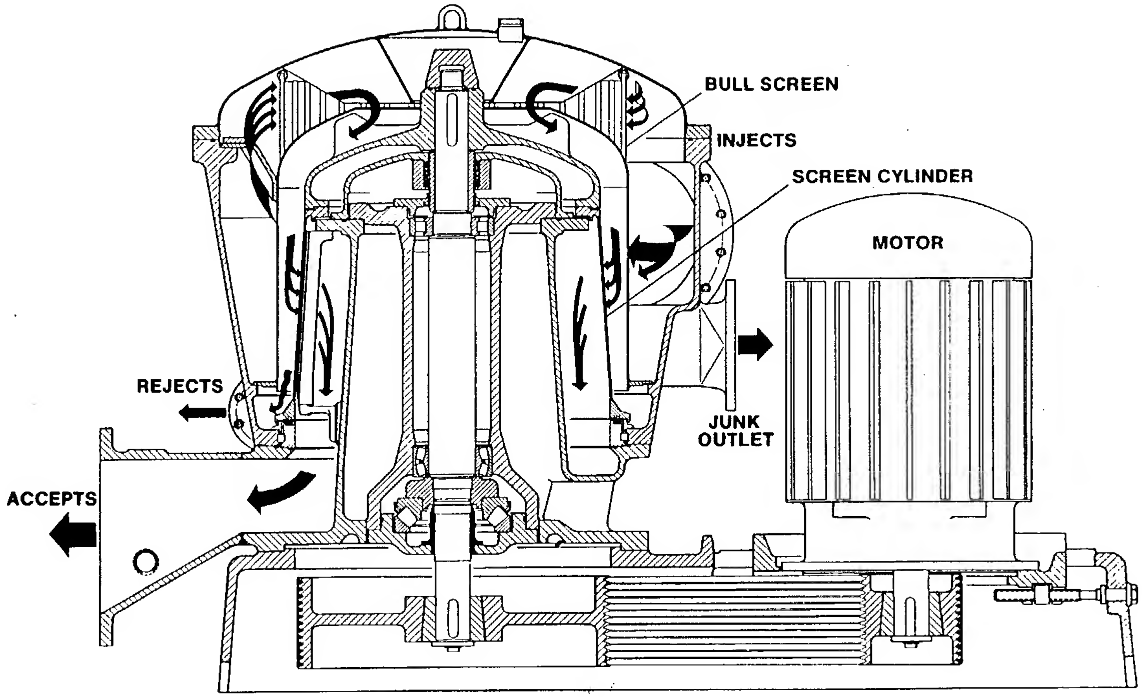

FIGURE 9-23. Pressure screen (KMW).

Gravity Centrifugal Screens

The gravity centrifugal screen (Figure 9-22) overcame many of the problems of the vibratory screen. This design utilizes a horizontal cylindrical screen plate with round holes up to 3 mm in diameter, depending on service. A "paddle-wheel" type rotor keeps the screen plate clean. Since the unit doesn't vibrate, heavy foundations and isolation mountings are not required. Foam generation is reduced, but not eliminated.

The principle of the screen is based partly on the fact that good fiber tends to be thoroughly hydrated and has a specific gravity close to water. When the low-consistency pulp stock is rotated in the centrifugal screen, the fibers align themselves with the direction of flow, which is predominantly through the circular holes in the screen plate. The coarse materials are not fully hydrated and have a lower density; this factor limits the effect of centrifugal force and the coarse materials tend to be carried across the screen plate to discharge as rejects. The coarse material accumulates as it moves axially, and this loose mat also acts to some extent as a screening element. Gravity centrifugal screens have been applied to a wide range of stock screening applications (7).

Pressure Screens

The operating principle of pressure screens is similar to gravity centrifugal screens. The distinction is that they operate under full line pressure and the radial flow within the unit can be either centrifugal (outward), centripetal (inward) or a combination depending on design. They have the advantage of high capacity per unit, flexibility of physical location, small space requirements and economy of piping and pumping. The totally enclosed design excludes air entrainment and minimizes slime buildup.

Pressure screens were first used in paper machine approach systems where their main function was to remove gross contaminants and protect the paper machine forming fabric. More recently, with refinements and modifications in design, various configurations are being utilized in virtually all fine screening applications. Examples of current designs are illustrated in Figures 9-23 and 9-24.

All pressure screens utilize a cylindrical, perforated plate. The most common plate-cleaning mechanism is a rotating hydrofoil (Figure 9-25), but other types of rotating cleaning elements are successfully utilized, depending on screen design. Four different flow patterns are offered in commercial units (Figure 9-26); at least two designs utilize two concentric screen plates with both inward and outward flows.

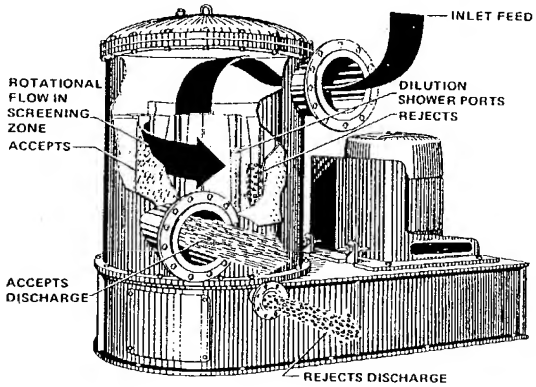

FIGURE 9-24. Pressure screen (Hooper).

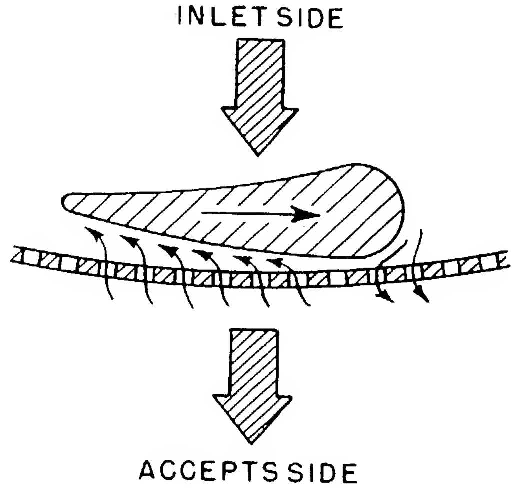

FIGURE 9-25. The principle of a typical pressure screen is illustrated. The leading edge of the rotating foil accelerates the stock. The negative pulse under the sweeping foil momentarily reverses the flow, effectively purging the screen openings.

Mechanism of Debris Removal

Four possible mechanisms have been hypothesized for debris removal in a pressure screen:

1) Positive size separation - this applies only to rigid particles that are larger in all three dimensions than the screen plate openings
2) Debris orientation - long debris particles which would be accepted at a certain orientation are rejected because the "angle of approach" is steeper.
3) Fiber network - fibers and debris particles on the inlet side form a network having small openings that prevent passage of debris particles.
4) Fluid forces - elongated particles from the screen plate openings are recaptured to the inlet side due to fluid forces induced by the pulsating element.

Most investigators focus on the first two mechanisms. The major design and operating parameters of flow configuration, screen plate openings, rotor type and speed, and stock consistency can shift the dominance from one mechanism to another.

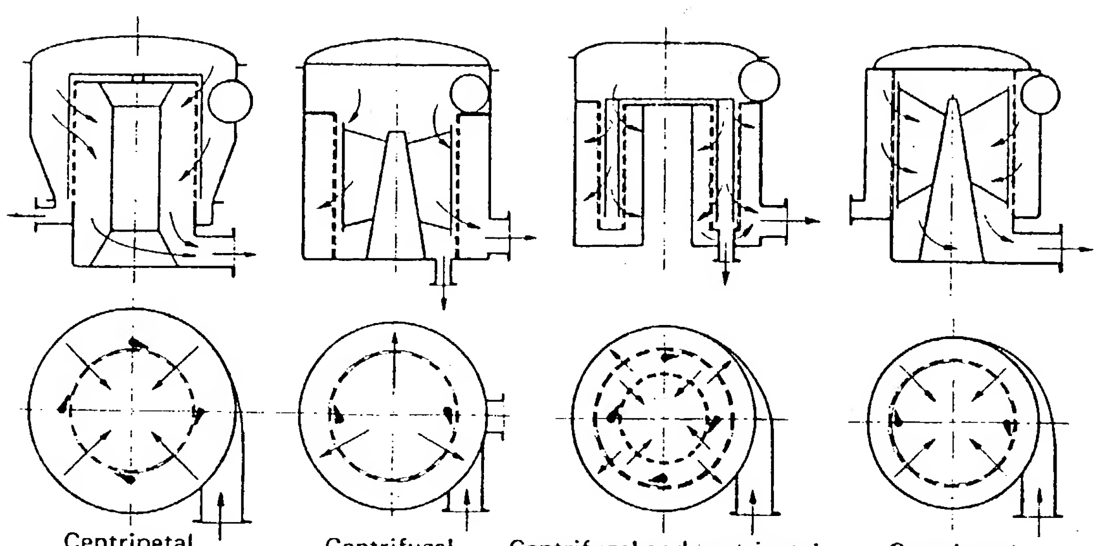

FIGURE 9-26. Four pressure screen flow configurations.

Design Choices

Modern pressure screen plates are precision manufactured components. They are normally fabricated from 316L stainless steel or better and are electropolished after machining to remove tiny residual burrs which might encourage "stringing". Either holes or slots may be used as screen perforations depending on requirements.

Traditionally, holes were punched in flat plates, which were then rolled into cylinders. Today, most holes are taper-drilled, i.e., cylindrical on the feed side and conical on the accept side to reduce the pressure drop across the thick plate. Hole spacing in the direction of rotation must be sufficient to avoid "hairpinning" of fibers between two holes. Because of this requirement, the open area of very fine screens may be as low as 10%.

Screen slots are normally produced using saw cutters of the desired nominal slot width. As with holes, the nominal slot width is only through a small fraction of the plate thickness on the feed side; the accept side is normally "relieved" with a much wider cutter to reduce the pressure drop. Slots are oriented perpendicular to the direction of rotor rotation so the long dimension of the debris particle is presented to the slot width. Slot widths are always less than hole diameters, so slots are more effective in removing small cubical debris. However, slotted screen open areas are generally in the 3 to 7% range, so throughput is lower than for screen cylinders with holes. Because of lower structural integrity, slotted plates are made of thicker plate.

In the late 1970's and early 1980's screen cylinders with contoured surfaces were introduced. The contoured surface in conjunction with the action of the rotor tends to introduce microturbulence which disrupts and fluidizes the mat of fibers. This action permits the opening to pass more fibers before a mat forms. Contoured surfaces generally have greater throughput, handle higher feed consistencies, and operate at lower reject rates than smooth-surfaced cylinders. Contoured screen cylinders are available in a variety of contour levels. Fluidizing and other effects are dependent on the degree of surface contour as well as on rotor design and speed.

Measuring Screen Performance

Two indices are generally accepted for measuring screening efficiency. Using nomenclature from TAPPI TIS 0605-04:

(1) Debris Reject Efficiency, (E_R)

$$E_R = \frac{S_r}{S_i} \cdot R_w$$

where:

R_w = Reject rate, decimal portion of inlet weight flow

S_r = % debris by weight in reject flow

S_i = % debris by weight in inlet (feed) flow

(2) Cleanliness Efficiency, (E_C)

$$E_C = \frac{S_i - S_a}{S_i} = 1 - R_w$$

where:

S_a = % debris by weight in accept flow

Note: The ratio S_a/S_i is known as the cleanliness ratio.

For relatively large debris, the efficiency can be 100%. For intermediate-size debris, the efficiency is strongly affected by the % reject rate (RW):

$$RW = \frac{\text{amount of pulp rejected}}{\text{amount of pulp fed}} \times 100$$

Both gravity and pressure screens require a significant reject rate in order to ensure a sufficiently low level of debris in the accepted stock. The typical relationship is illustrated in Figure 9-27. Numerical values of efficiency are rather meaningless unless the efficiency measurement itself is defined and unless the reject rate is reported. Obviously, the efficiencies of two screens with different reject rates can not be compared meaningfully.

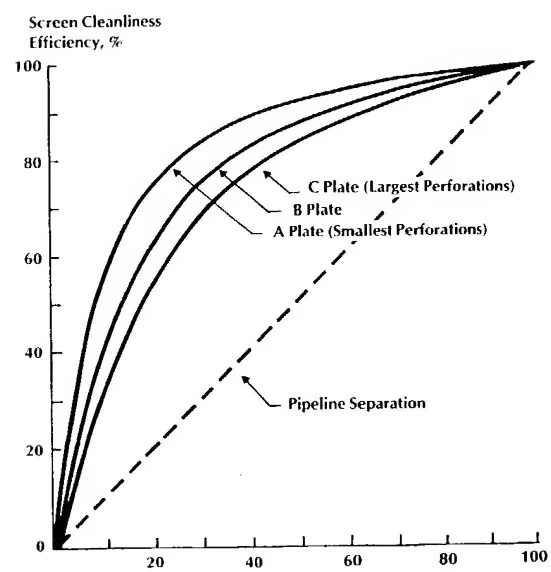

FIGURE 9-27. Effect of reject rate and plate opening on screening efficiency.

To overcome these problems, Nelson (9) has proposed using what he calls the "Screening Quotient" (Q), equal to E_C/E_R. This parameter is

$$Q = \frac{S_r - S_a}{S_r}$$

relatively constant with changes in reject rate. Also:
where:
S_r = % debris by weight in rejects

Therefore, only two pulp samples need to be taken and analyzed in order to calculate Q.

In order to measure screen performance by any of the above criteria, it is necessary to measure debris content on selected samples quantitatively. The traditional method utilizes a laboratory flat screen (Somerville or Valley) with slot widths between 0.10 and 0.25 mm (0.004 to 0.010"). Alternative methods have utilized the Pulmac shive analyzer, Van Alfthan shive analyzer, and PFI mini-shive analyzer. More recently, electron image analyzers have allowed investigators to quickly determine debris removal efficiency without time-consuming "wet" laboratory tests.

When screens are rejecting debris, there is an accompanying tendency to reject long fibers. This feature of screens is sometimes exploited for stock fractionation. Rejection of long fibers can be measured quantitatively by the same types of formulas as for debris when the long-fiber fraction is defined and measurable. Since for most applications it is desirable to maximize screening efficiency (E_R) and minimize long fiber rejection (L_R), it has been proposed that the "quality of screening" can be measured by the difference between E_R and L_R at a given reject rate. Comparisons of the "quality of screening" between different systems are meaningful only when the size distributions of the stocks to be compared are similar.

Variables Affecting Screen Performance

A listing of the major design and operating variables affecting screening is given in Table 9-3. Many of these variables are strongly interrelated. For example, operating with a higher stock consistency, and/or using larger screen plate perforations will provide increased capacity, but usually at the expense of screening efficiency. In applications where high efficiency is essential, it is advisable to use the shape of perforation and the smallest perforation opening that experience has shown work best on the particular type of fiber and debris.

TABLE 9-3. Variables affecting screening performance.

Stock Characteristics
- type of fiber
- characteristics of debris
- debris level

Design of Screen
- flow configuration
- type of plate-cleaning mechanism
- type of perforation (holes or slots)
- rotor speed (rpm)

Operating Variables
- stock flow rate (or pressure drop across screen)
- feed consistency
- reject rate
- screen plate perforation size
- stock temperature
- dilution flow to screen

All gravity screens and some pressure screens require dilution on the feed side near the reject outlet because water with the inlet stock preferentially flows through the perforations, leaving the freer pulp and debris in a concentrated form. Proper control of the amount of dilution is important to prevent rejecting excessive good fiber (too much dilution) or allowing considerable debris to pass through the screen openings (insufficient dilution).

References (9) and (10) provide a more complete discussion of the various factors affecting screen operation.

Arrangement of Screens

Because a large reject flow is required from the primary pulp screens in order to achieve adequate debris removal efficiency, additional stages of screening are performed on the reject stream to concentrate the debris and return the good fiber to the process. A simplified "cascade arrangement" of screens is shown in Figure 9-28. The final reject stream of shives or slivers is often refined into acceptable fiber, with only a small system bleed taken from the centricleaning step following refining. However, in high-quality bleach kraft mills with a history of periodic plastic contamination in the pulp stock, refining is avoided, and last-stage screen tailings are removed from the system and either burned as fuel or consigned to landfill.

Where required, mills can employ a more sophisticated flow sequence for screening and handling of refined rejects. For example, the TMP system illustrated in Figure 9-29 utilizes two primary stages in series and direct addition of cleaned, refined rejects into the accept stream. In situations where two primary stages are employed in series, it is usually advantageous to use holes for the first-stage screen plates and slots for the second stage.

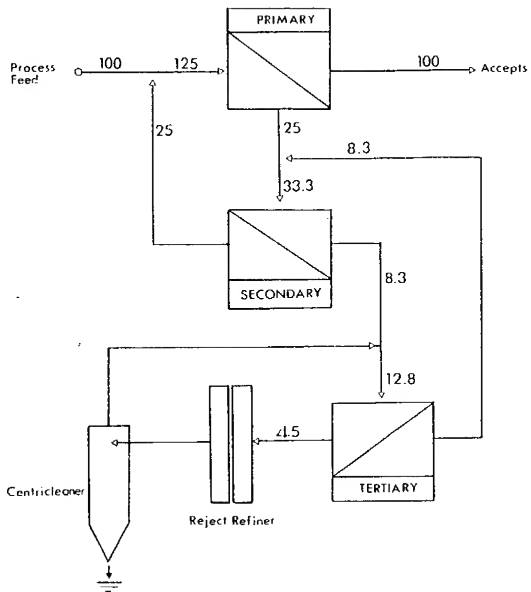

Figure 9-28. Three-stage cascade screening system showing a representative moisture-free stock balance. The balance is based on a feed rate of 100, 20% primary-stage reject, 25% secondary reject, 35% tertiary reject and negligible cleaner reject.

9.5 CENTRIFUGAL CLEANING

Up to the 1940's, high specific gravity contaminants such as sand and dirt solids were usually removed from pulp suspensions in a "riffler". This device was essentially a modified settling trough through which low-consistency stock was slowly channelled, allowing the heavier particles to settle out. These units were bulky, inefficient, and required frequent manual cleaning.

A better method was provided through application of the centrifugal cleaner. The classic centrifugal cleaner (illustrated in Figure 9-30) was patented in 1891, but did not come into widespread use until the 1950's. This device (also identified by such terms as liquid cyclone, hydrocyclone, vortex cleaner or, more simply, "centricleaner") consists of a conical or cylindrical-conical pressure vessel with a tangential inlet at the largest diameter of the cone or cylinder. Also centered axially at the large diameter end is the vortex finder or accepts nozzle. At the opposite end or minimum-diameter end is the underflow tip or rejects nozzle.

The centrifugal cleaner removes unwanted particles from pulp and paper stock by a combination of centrifugal force and fluid shear. Therefore, it separates both on the basis of density differences and particle shape. All centrifugal cleaners work on the principle of a free vortex generated by a pressure drop to develop centrifugal action. The power source is the pump. The stock enters the cleaner

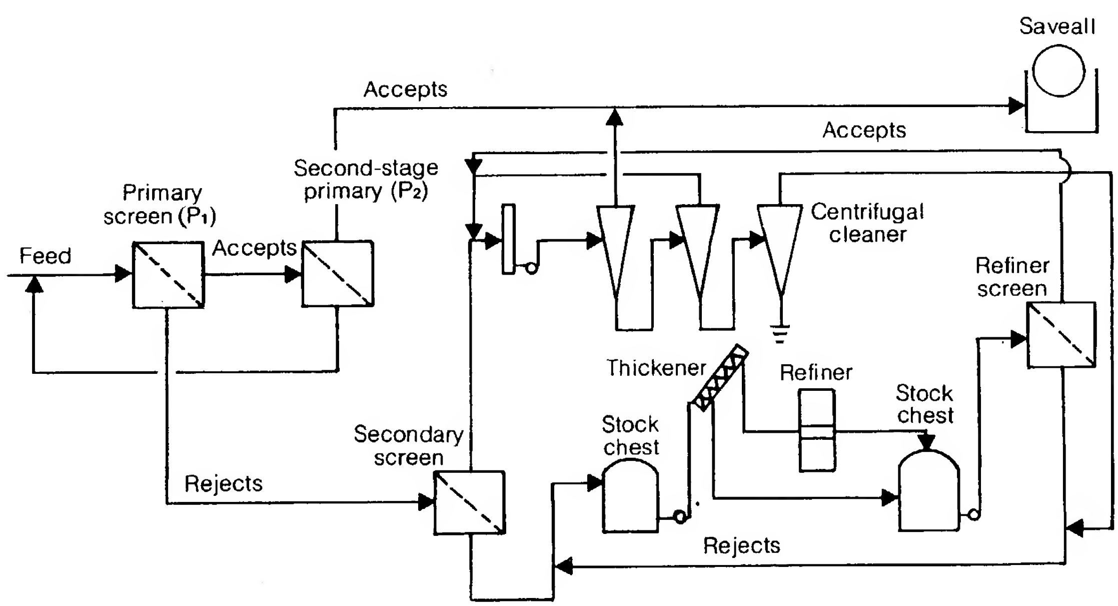

Figure 9-29. Two-stage primary screening system for producing high-quality TMP stock (S.W. Hooper Corp.).

tangentially; the inlet scroll guides the flow to impart a rotating motion. As the stock flows inward, the velocity increases, resulting in high centrifugal forces near the center which carry dense particles outward and away from the accepted stock. Good fiber is carried inward and upward to the accepted stock outlet. The dirt, held in the downward current, continues toward the tip. As the diameter narrows, the flow is forced inward against increasing centrifugal force (several hundred g's), which concentrates the dirt and releases good fiber to the accepts flow.

Small-diameter cleaners develop the highest centrifugal forces, and are most effective for removing various types of small dirt particles. Where cleaners are employed principally to remove larger, less-dense particles (e.g., shives and slivers), as in paper machine approach systems, larger-diameter cleaners have proved to be more effective. The comparative efficiencies of two different-diameter cleaners with respect to particle size and shape are illustrated in Figure 9-31.

A stable air core is established in the center of the centrifugal cleaner over its entire length by the hydraulic flow patterns. The diameter of the air core is dependent on the dimensions of the cleaner, its operating conditions, and the air content of the stock. If the underflow tip is exposed directly to the

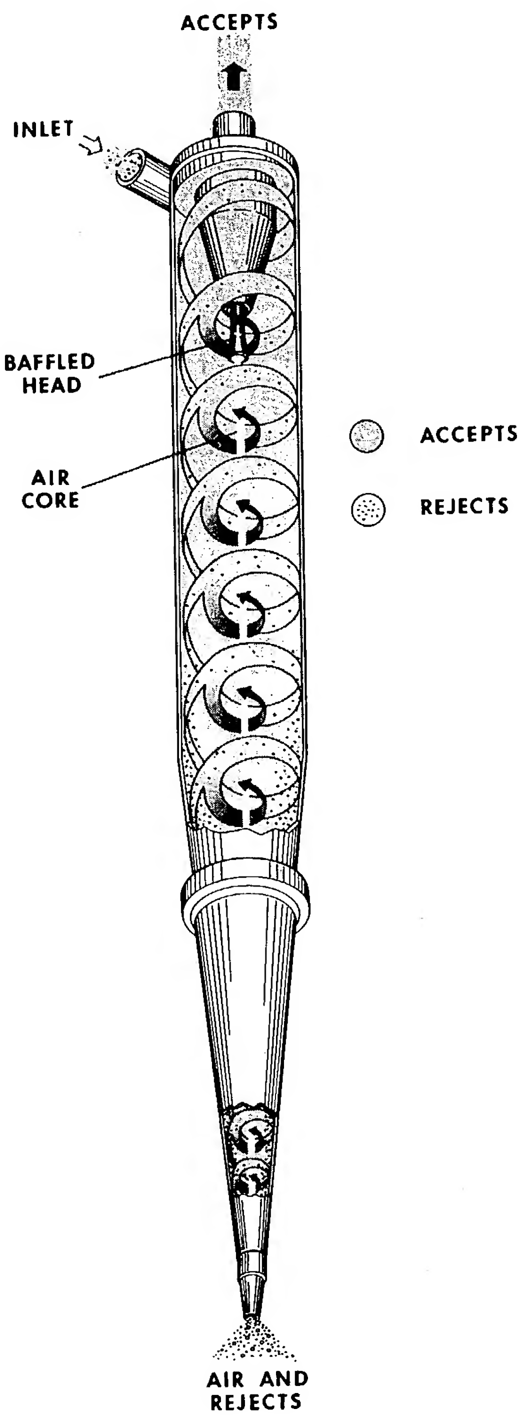

FIGURE 9-30. Schematic of a centrifugal cleaner (Bird Machine Co.).

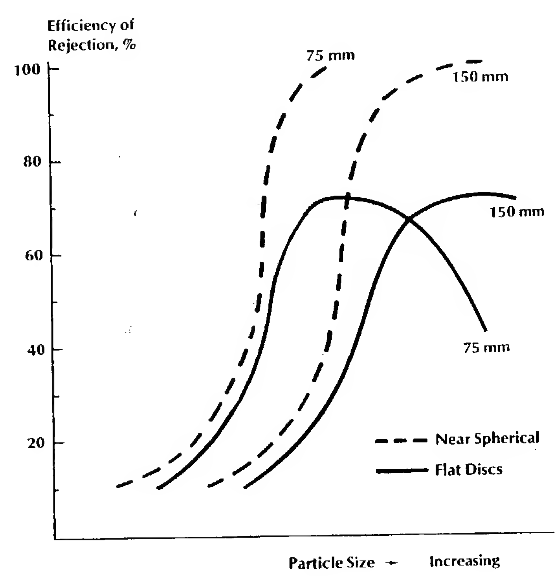

FIGURE 9-31. Effect of particle size and shape on efficiency of rejection from 75-mm and 150-mm centrifugal cleaners.

atmosphere, the cleaner will draw additional air up the core and discharge it with the accept flow; this can be a problem in some applications, notably in the approach system to a paper machine.

In addition to the basic flow pattern within the cleaner, numerous eddies are produced which are wasteful of hydraulic energy and detrimental to cleaning efficiency. Manufacturers have modified the basic design in various ways in an effort to minimize or overcome these secondary flow patterns.

Variables Affecting Cleaner Performance

The performance of a centrifugal cleaner is usually measured in terms of its ability to remove dirt particles:

$$\text{\% Efficiency} = \frac{\text{Dirt Count}_{(\text{Feed})} - \text{Dirt Count}_{(\text{Accept})}}{\text{Dirt Count}_{(\text{Feed})}} \times 100$$

As with screens, the efficiency of dirt removal is markedly affected by how much stock is rejected. Therefore, comparisons between cleaners at different reject rates can be misleading. Typically, the reject rate is in the range of 10 to 20%. Some cleaners are equipped with a "stock saver" attachment below the cone, where some good fiber is refloated into the cleaner core using "elutriation" (dilution water).

A listing of the major design and operating variables is given in Table 9-4. Cleaning is commonly carried out at relatively low consistencies, under 1%, and efficiency in most applications is adversely affected if consistency is increased much above this level. The amount of pressure drop determines the hydraulic capacity of the cleaner and is a measure of how much centrifugal action is developed. Most units operate with a pressure drop of 30 to 35 psi. A more complete discussion of operating variables is given in reference (11).

Operating Problems

The principal operating problem with centrifugal cleaners is plugging of the reject orifice with foreign materials, fiber flocs, or high-consistency stock. The orifice is usually sized to maintain a reasonable reject level, but sometimes the orifice size must be increased to avoid plugging. The largest orifice at a given reject rate is obtained at minimum back pressure on the cleaner. Due to thickening action at the tip, the reject consistency may be three times that of the inlet; feed consistency can sometimes be lowered to reduce plugging. Some cleaner installations are "protected" with a large-diameter centrifugal cleaner to remove coarse materials likely to plug smaller units (e.g., Figure 9-32). In some cases, a deflocculating screen ahead of the cleaners is helpful in eliminating fiber lumps that might contribute to plugging.

TABLE 9-4. Variables affecting centrifugal cleaner performance.

Stock Characteristics
- type of fiber
- characterization of contaminants (size, shape, density)
- dirt level

Design of Cleaner
- body diameter
- feed inlet configuration
- diameter of accept nozzle/vortex finder
- height of cylindrical section
- angle of cone
- application of spiral grooves
- method of reject rate control (fixed orifice and back pressure)

Operating Variables
- stock flow rate
- pressure drop across cleaner
- feed consistency
- reject rate
- stock temperature
- air in stock
- elutriation (when used)
- back pressure
- discharge chamber configuration

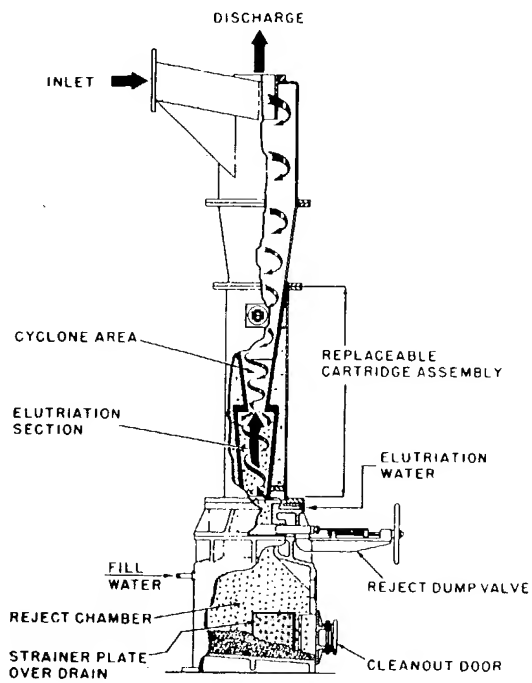

FIGURE 9-32. Centrifugal cleaner designed for heavy trash removal (Black Clawson).

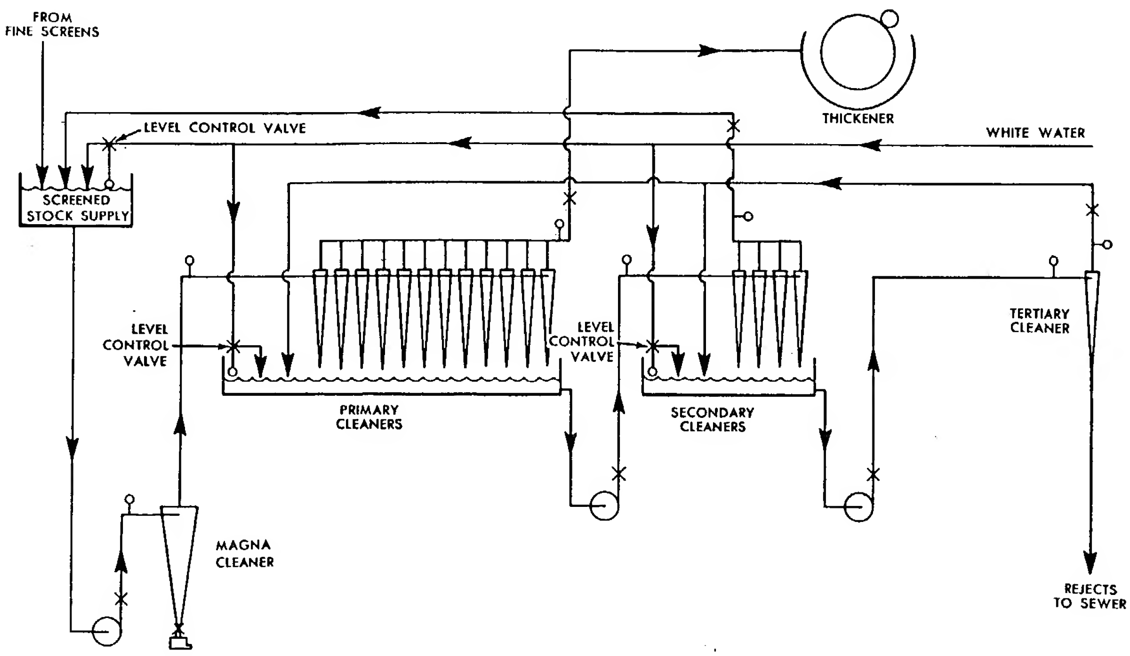

FIGURE 9-33. Flow chart for three-stage centrifugal cleaning system (Sproat Bauer).

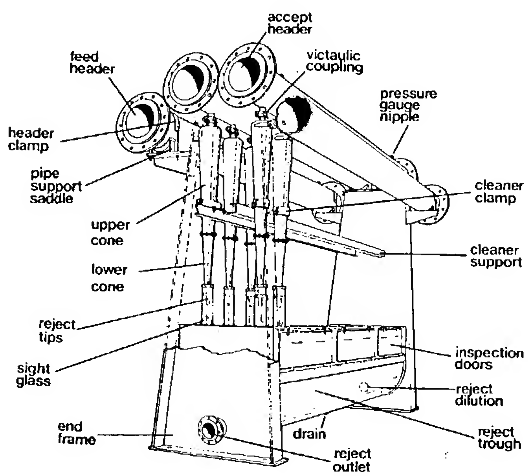

FIGURE 9-34. Module of vertical centrifugal cleaners (Hymac Ltd.).

Arrangement Of Cleaners

Cleaners are typically employed in a cascade sequence similar to that used for screens. Because a large reject flow is necessary for good operating efficiency, additional stages are required to concentrate the dirt in the reject stream and return good fiber to the process. A three-stage arrangement is illustrated in Figure 9-33. The amount of rejected fiber is usually less than 1%.

The early cleaner installations consisted of large numbers of individual units in an open vertical arrangement with hose attachments to the feed and accept headers and open discharge to the reject trough. A more updated open vertical grouping is depicted in Figure 9-34. Most of the newer installations are made up of containerized groupings of cleaners in housings and cassettes of varying design. The stacked, horizontal arrangement of cleaners provides significant space savings, while the enclosed construction promotes good housekeeping. Examples of a modern housing and an individual cleaner unit are shown in Figures 9-35 and 9-36.

Design Modifications

Three types of centrifugal cleaners are used in the pulp and paper industry. The original application, the removal of heavy debris (specific gravity greater than 1.0), employs the classic design of centrifugal cleaner, which is now more precisely designated as "forward cleaning". Forward cleaners still account for the great majority of installations.

Reverse-flow and through-flow cleaners are used principally to remove light debris (specific gravity less than 1.0) in secondary fiber pulping operations. Reverse-flow cleaners came into common use in the late 1970's, but since the mid 1980's have been displaced by through-flow cleaners because of lower pressure drop requirements and low hydraulic reject

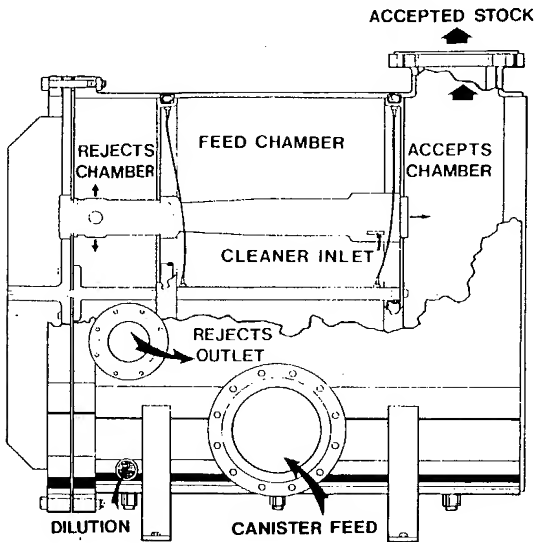

FIGURE 9-35. Modern canister housing for centrifugal cleaners (Black Clawson Co.).

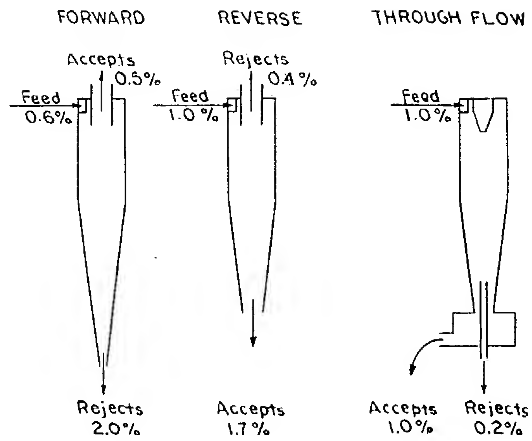

FIGURE 9-37. Flow configurations for forward, reverse-flow and through-flow cleaners, also showing typical operating consistencies.

rates (12). Figure 9-37 illustrates the general orientation and typical consistencies for each type of cleaner.

9.6 THICKENING

Following low-consistency operations such as cleaning and screening, it is necessary to thicken the stock (with or without washing) prior to the next process operation. A variety of equipment is available for this purpose (see Table 9-5) depending on requirements.

In many instances, a simple increase in stock consistency to the 4 – 8% range is required. For this service, a gravity thickener (usually called a decker) is commonly used, as illustrated in Figure 9-38. Water flows into the cylinder by virtue of the difference in liquid level between the vat and cylinder; pulp is retained on the rotating cylinder and is couched off by a rubber roll.

Less commonly, an increase in consistency to the 3.5 – 4.0% range is sufficient and can be achieved using a slusher. This type of thickener is similar to the decker except no couch roll is used. Rather, the stock moves from the inlet side of the vat through the dewatering zone to the other side of the vat, where the thickened stock is discharged, usually with the help of a continuous shower. The principle of operation is illustrated in comparison with a decker in Figure 9-39.

TABLE 9-5. Thickening equipment applications.

Equipment	Discharge Consistency (%)	Washing Capability
Slusher	3.5 – 4	none
Gravity Thickener	4 – 8	none
Valveless Filter (Internal Dropleg)	9 – 12	some
Vacuum Filter	12 – 15	great
Multidisc Filter	10 – 12	none
Screw Extractor	>20	none
Various Press Designs	>20	none → great

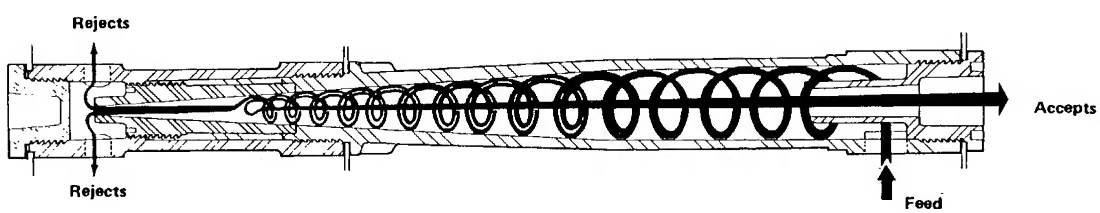

FIGURE 9-36. Individual cleaner unit mounted in canister housing (Black Clawson Co.).

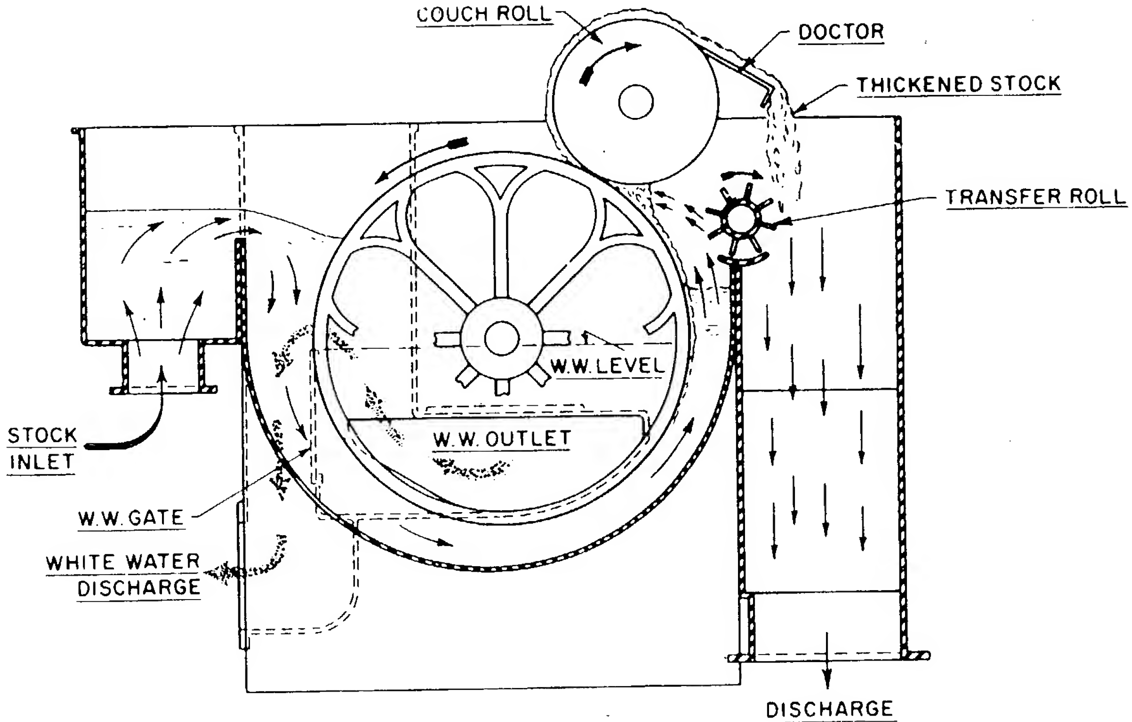

FIGURE 9-38. Gravity couch roll-type thickener for pulp stock (Black Clawson Co.).

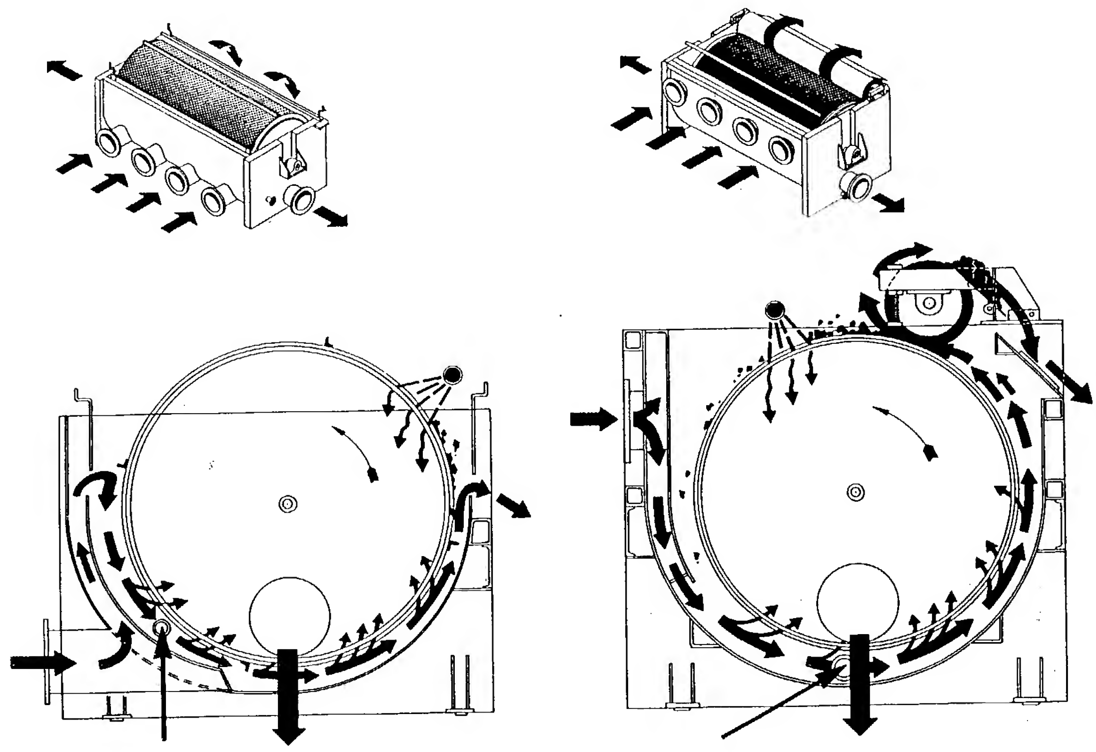

FIGURE 9-39. Comparison between slusher and gravity thickener (Hymac Ltd.).

For intermediate levels of thickening (10–12%), the so-called valveless washer can be used (see Figures 9-40 and 9-41). When thickening from a low consistency below 0.7% to a level of 10 - 12%, a two-stage operation may be required as illustrated in Figure 9-42.

To achieve consistencies of 12 – 16% and also wash the stock, it is necessary to use a vacuum washer. All equipment of this type functions by applying vacuum over the forming and washing zones, then cutting off the vacuum by means of an internal valving arrangement to allow the thickened sheet to be discharged. The suction effect is typically produced by the filtrate dropleg which discharges into a seal tank (refer to Figure 9-43). The pulp mat is discharged from the washer mould by takeoff rolls or doctors. The mesh face is often shower-cleaned prior to re-submergence in the vat.

Vacuum washers differ in design with respect to the valving arrangement. In Figure 9-43, the valve is anchored to one end of the vat. In Figure 9-44, the independent box-shaped valve is riding on its seat at

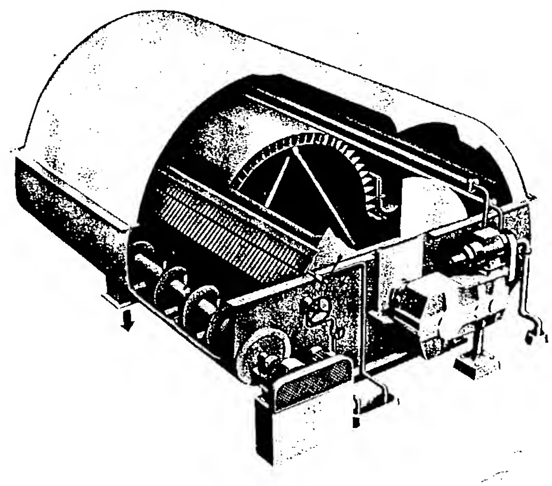

Figure 9-40. Valveless filter with internal dropleg (Beloit Rauma).

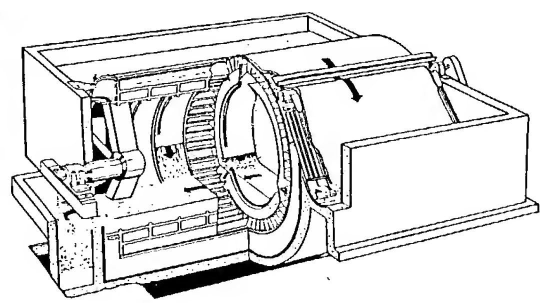

Figure 9-41. Valveless vacuum filter (Impco/Ingersoll Rand).

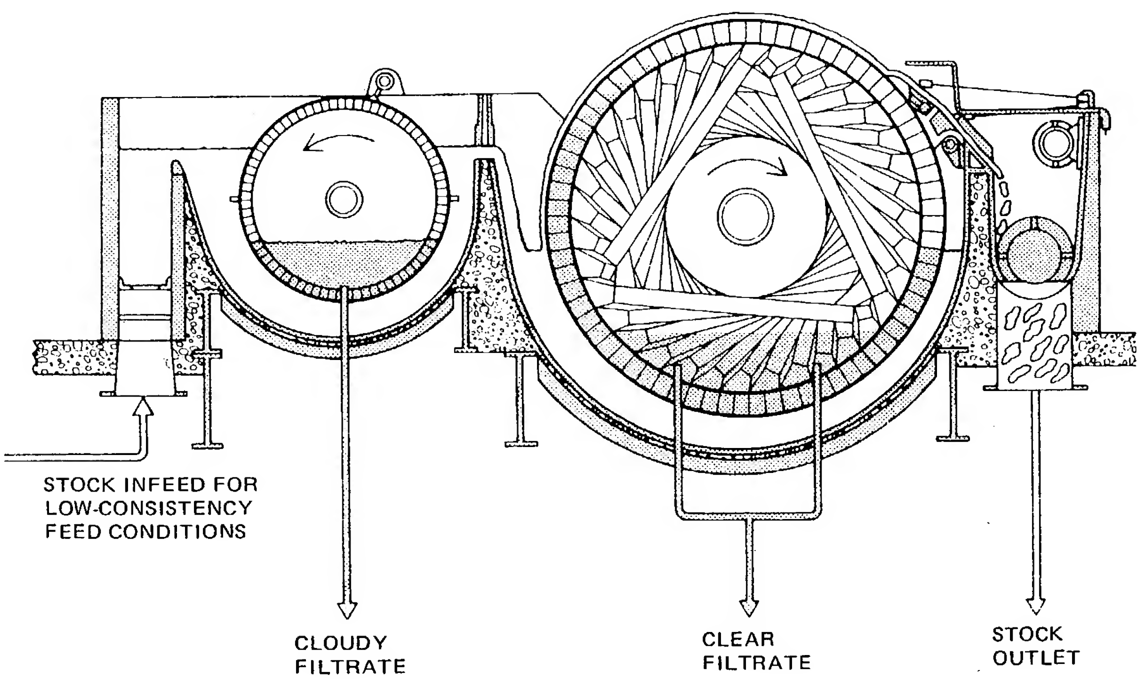

Figure 9-42. Two-stage thickening system consisting of a slusher followed by a valveless filter (Beloit Corp.).

the outer center of the cylinder. In Figure 9-45, the valve is held stationary by a fixture passing through the rear trunnion. Another design shown previously (refer back to Figure 9-4) utilizes a valve located directly on the trunnion.

For simple thickening of very dilute stocks up to 12% consistency, multidisc thickeners of the type illustrated in Figure 9-46 can be used. A fiber mat forms on the face of each sector as it submerges in the vat of stock. After complete submergence, vacuum is applied and more pulp is deposited while filtrate is drawn through the mat. The initial filtrate is relatively cloudy and can be segregated (by the action of the end valve) for dilution uses. The later

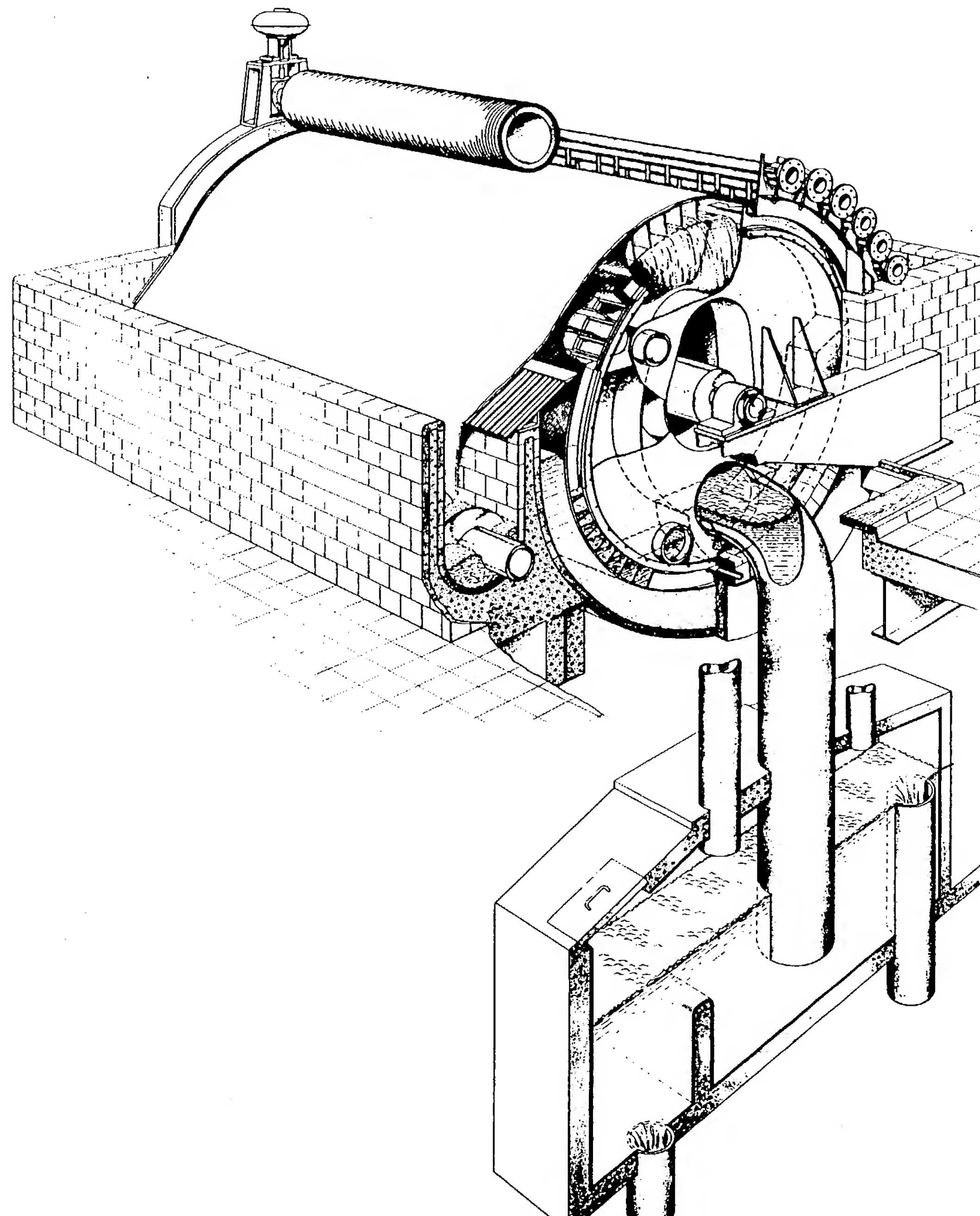

FIGURE 9-43. Vacuum washer illustrating configuration of dropleg and seal tank (Sandy Hill Corp.).

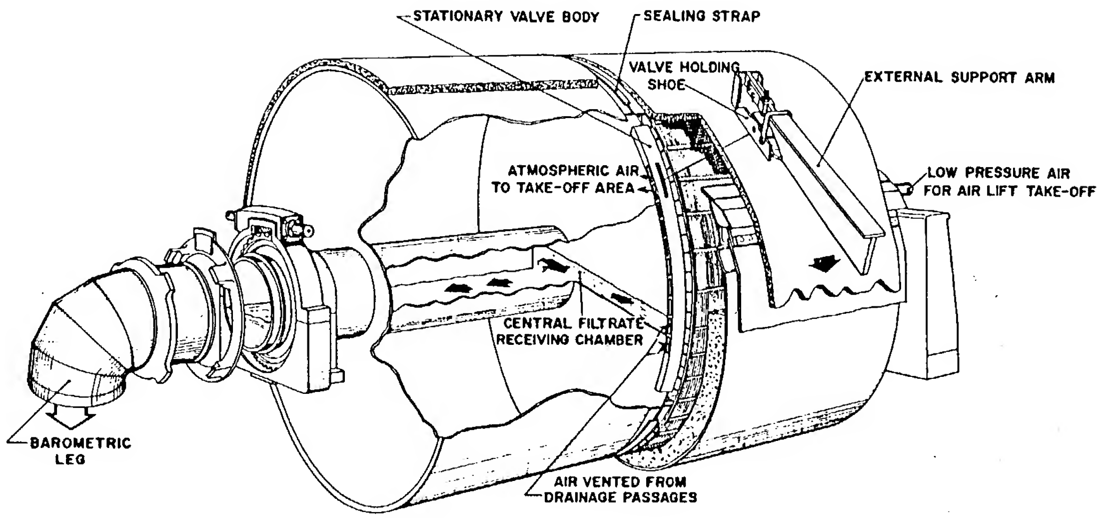

FIGURE 9-44. Circumferential valve vacuum filter (Impco/Ingersoll Rand).

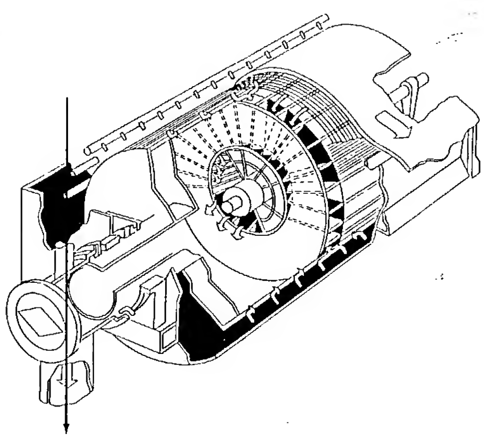

FIGURE 9-45. Center valve vacuum filter (Dorr-Oliver Inc.).

(clear) filtrate is sufficiently free of fiber to be used for shower water. Following emergence from the vat, the pulp mat is further dewatered and finally removed from the filter media by a knockoff shower. Multidisc thickeners are most commonly used as saveall devices, i.e., to recover fine fibers from white water and reuse the water.

To achieve stock consistencies above 15%, some type of screw extractor or press arrangement is usually employed. Representative examples of screw presses are shown in Figures 9-47 and 9-48.

9.6 STOCK PUMPING AND HANDLING

Efficient movement of stock through the various processing steps is at the heart of a pulp and paper mill operation, and no mill can operate successfully without reliable pumping units. Because centrifugal pumps have only one moving part and are usually driven directly from a synchronous motor, they are used wherever possible for stocks up to 6 - 7% consistency.

Centrifugal pumps for pulp and paper stocks are modelled on conventional water pump designs (Figure 9-49), but usually have modified impeller shapes (Figure 9-50) and wide clearances to assist the flow of stock through the pump passages. Several important factors must be considered when selecting a pump design, including consistency, fiber length, stock freeness, and the presence of additives.

For higher-consistency stock pumping, a number of special designs have traditionally been used. Figure 9-51 shows sections through a pump with double-meshing rotors. Figure 9-52 depicts a cutaway view of a double-rotor screw pump. Figure 9-53 illustrates a single-drive unit designed to pump over a wide range of consistencies up to 30%. These pumps are positive displacement and produce some pulsing; they all require the use of a feed chute or standpipe. A typical application is when pulp falls into a chute from a drum or diffusion washer and is pumped to the next stage of the system. Unfortunately, these devices are incapable of pumping high-consistency stock directly from a tank or bleach tower.

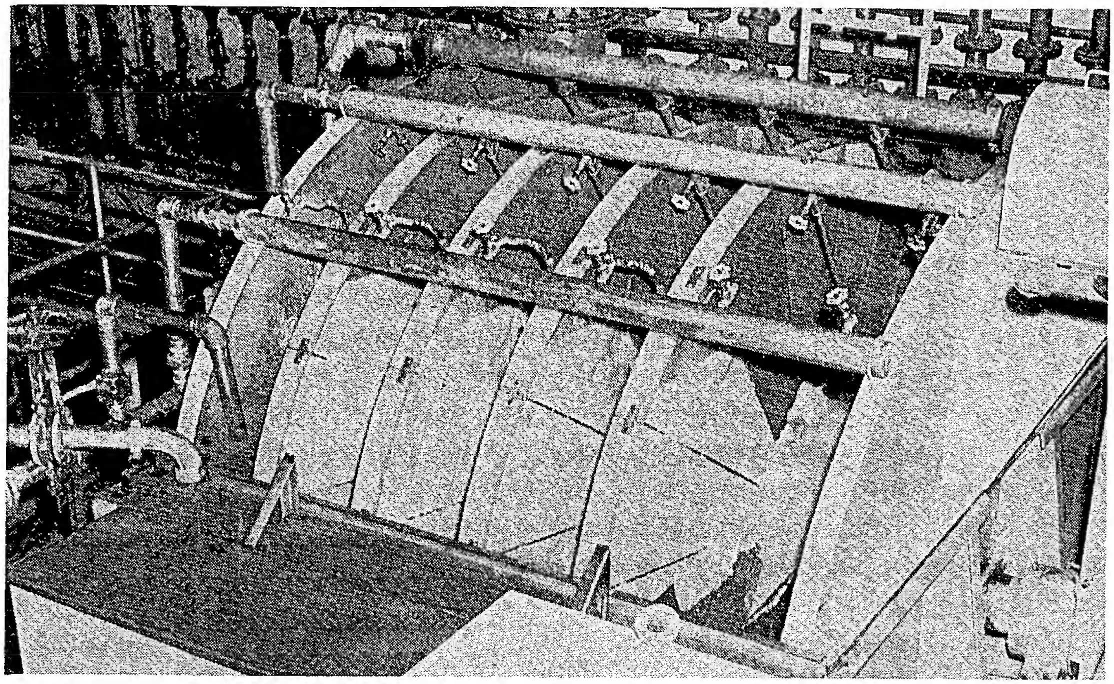

FIGURE 9-46. Multidisc filter utilized as a paper machine saveall (Impco/Ingersoll Rand).

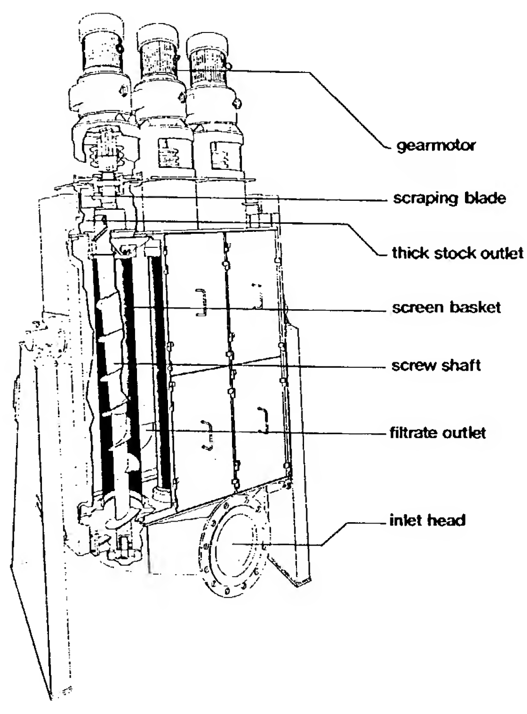

FIGURE 9-47. Three-screw extractor (Hymac Ltd.).

Medium Consistency Technology

Traditionally, the discharging/transporting of pulp from thick-stock storage or bleach towers involves bottom dilution, effective mixing, and pumping of a high-volume low-consistency stock. Often, the pulp must be re-thickened prior to the next processing step. These transport systems with auxiliary filtrate tanks, dilution pumps, controls, etc. are both capital- and energy-intensive. It has long been a goal within the industry to develop a single machine with which stock could be discharged from storage and transported without prior dilution and subsequent thickening.

The break-through occurred in the early 1980's with the introduction of a new line of equipment from Kamyr based on development work by Johan Gullichsen of Finland (13). Very quickly, a number of competitive medium consistency pumps and mixers were introduced, and the number of mill installations has soared. All units work on the same general principle: they generate shear forces high enough to fluidize pulp suspensions up to 12% consistency so that they behave like Newtonian fluids. Power consumption is minimized by keeping the active volume low. The principle of operation for the Kamyr unit is illustrated in Figure 9-54. Note that air separation and discharge are essential features of the system, since air would

otherwise accumulate in the eye of the pump. A competitive pumping unit is depicted in Figure 9-55.

The same principle has now been successfully applied toward the development of a device for screening pulp suspensions at medium consistency (8 - 15%). A prerequisite for a screening separation is the ability of fibers, knots, shives and other debris to move freely within the suspension. This is easily achieved at low consistency, but can also be accomplished by applying shear forces of an intensity sufficient for complete fluidization of the suspension at the face of the separating screen. The medium-consistency screen has a particulary great impact in mechanical pulping processes. Since latency can be removed by fluidization of medium-consistency fiber suspensions, there is no need to go below 10% consistency in any part of a RMP, TMP, CTMP or CMP line. This translates into a considerable reduction in the requirement for dewatering equipment.

9.8 PULP STORAGE AND BLENDING

In pulp and paper mills, storage of fiber stocks is necessary at appropriate points in the process to provide surge capacity and allow for interruptions in either supply or demand. A basic mechanical pulp mill may need substantial storage only at the end of the process. But, in a bleached kraft mill where significant interruptions can occur at several points in the process, storage capacity is a requirement at least after cooking and bleaching. Generally the blow tank provides several hours of storage, which is especially important with batch digesters to ensure a constant flow to the brown stock washers. (Refer also to Section 12.2.)

A traditional "high-density" storage chest (i.e., at 12 - 15% consistency) and pump-out arrangement is illustrated in Figure 9-56. The stock, usually conveyed from a washer/thickener, is dropped into the top of the chest. The pulp then moves downward as a plug with essentially no intermixing. At the bottom of the chest, a side-entry agitator provides mixing energy and a number of nozzles around the periphery supply dilution water. This arrangement, referred to as "zone agitation", reduces the pulp consistency to a fairly uniform level below 4%, suitable for conventional pumping. Additional dilution water is added at the pump suction for more precise consistency control.

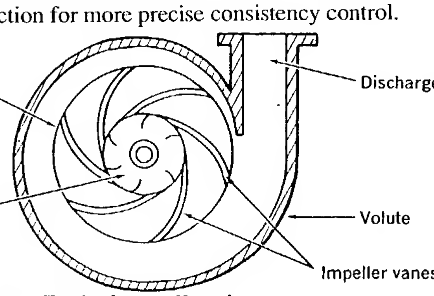

FIGURE 9-49. Typical centrifugal pump.

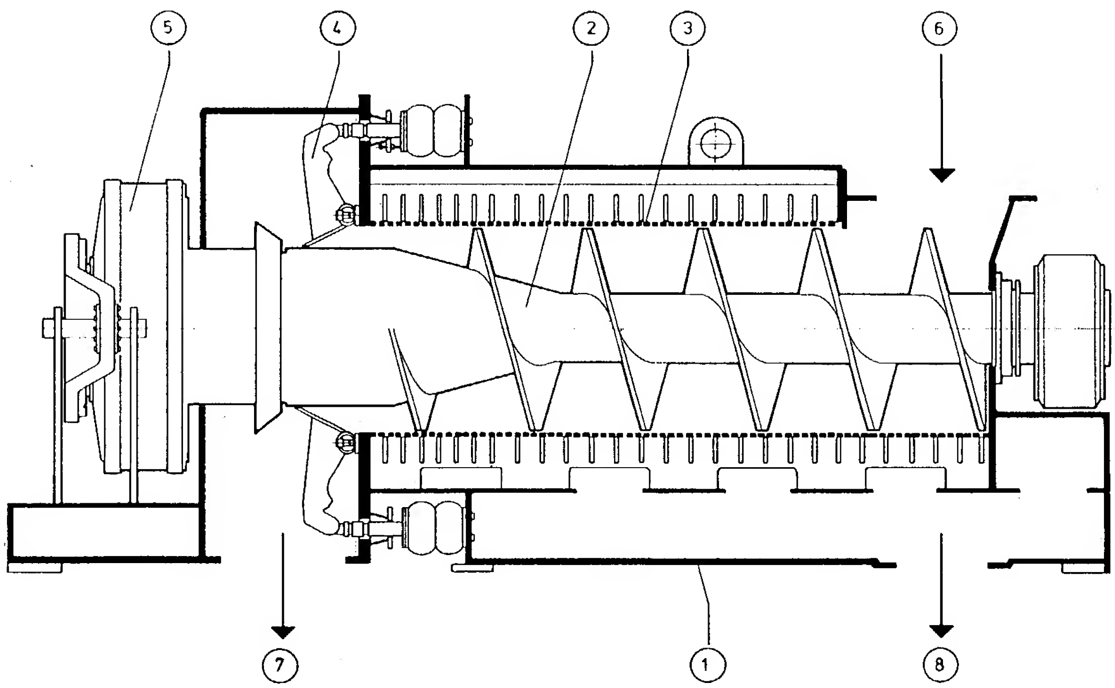

FIGURE 9-48. Screw press for dewatering pulp suspensions. (1) housing (2) screw (3) screen (4) discharging device (5) drive (6) inlet (7) outlet (8) filtrate (KMW).

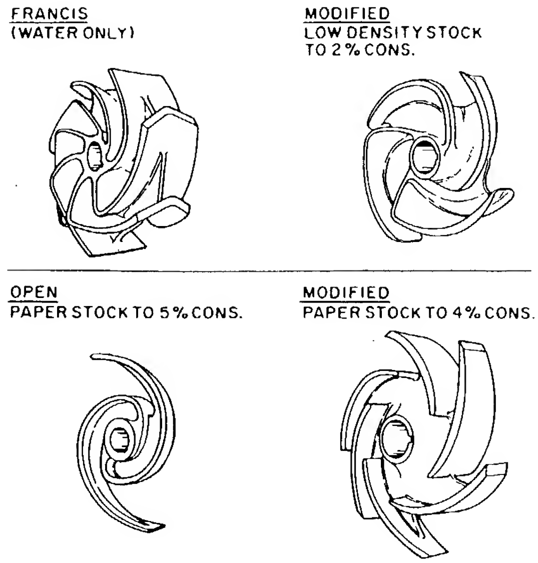

FIGURE 9-50. Centrifugal pump impellers for water and pulp stocks (Black Clawson Co.).

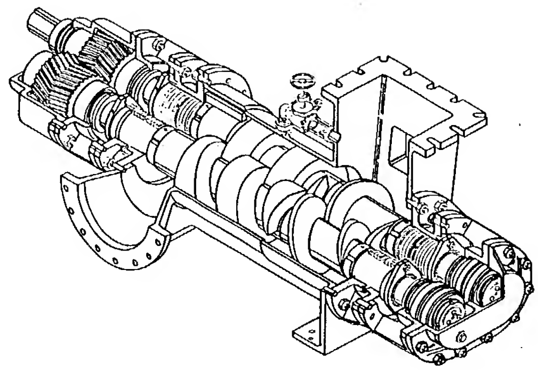

FIGURE 9-52. High density pump (Warren Pumps Inc.).

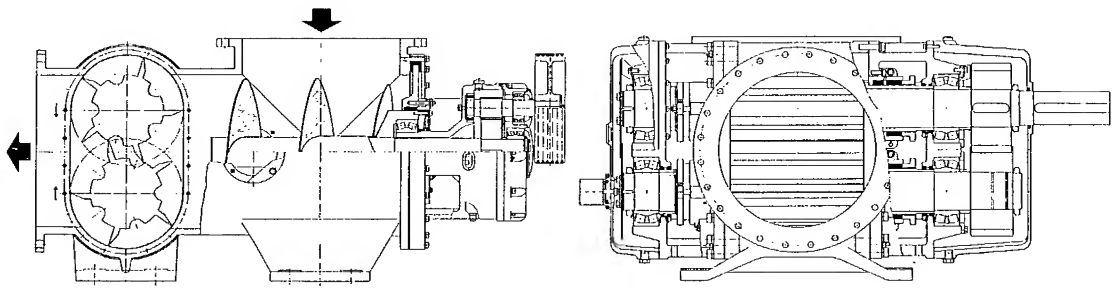

FIGURE 9-51. Thick stock pump utilizing double-meshing rotors (Beloit Rauma).

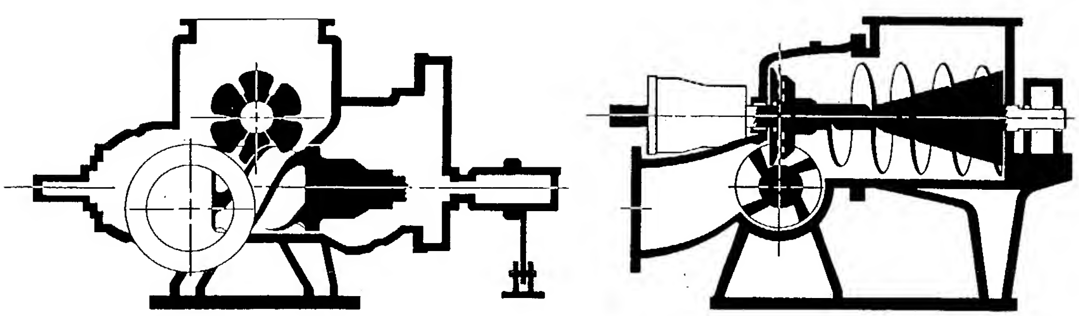

FIGURE 9-53. High density pump (Impco/Ingersoll Rand).

In newer installations that utilize the latest medium- consistency technology (refer to previous section), the arrangement can be greatly simplified. The medium-consistency pump can be coupled directly to the storage chest without the necessity of a dilution zone.

Blending

Because of a non-uniform wood furnish and variations in the pulping process, there is always corresponding variation in the quality and "processability" of mechanical and chemical pulps. Papermakers are well aware that thorough blending of the stock furnish ahead of the paper machine is essential toward avoiding upsets and producing a uniform product. It is surprising, therefore, that blending is often ignored as a process option within the pulp mill.

In the bleached kraft mill, a logical place for blending is following screening and prior to bleaching. Blending at this point will significantly reduce kappa number variation and make possible better bleaching control. The ideal arrangement is a large chest providing 3 to 4 hours of retention at a consistency below 4%, with sufficient agitation to ensure a high turnover rate. One method of blending within such a tank is illustrated in Figures 9-57 and 9-58. Another method of low-consistency stock blending utilizing a novel chest design is illustrated in Figure 9-59.

In mills that have more than one high-density

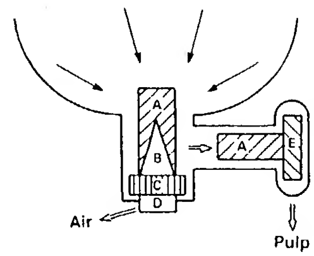

Figure 9-54. Schematic arrangement for Kamyr medium consistency pump.

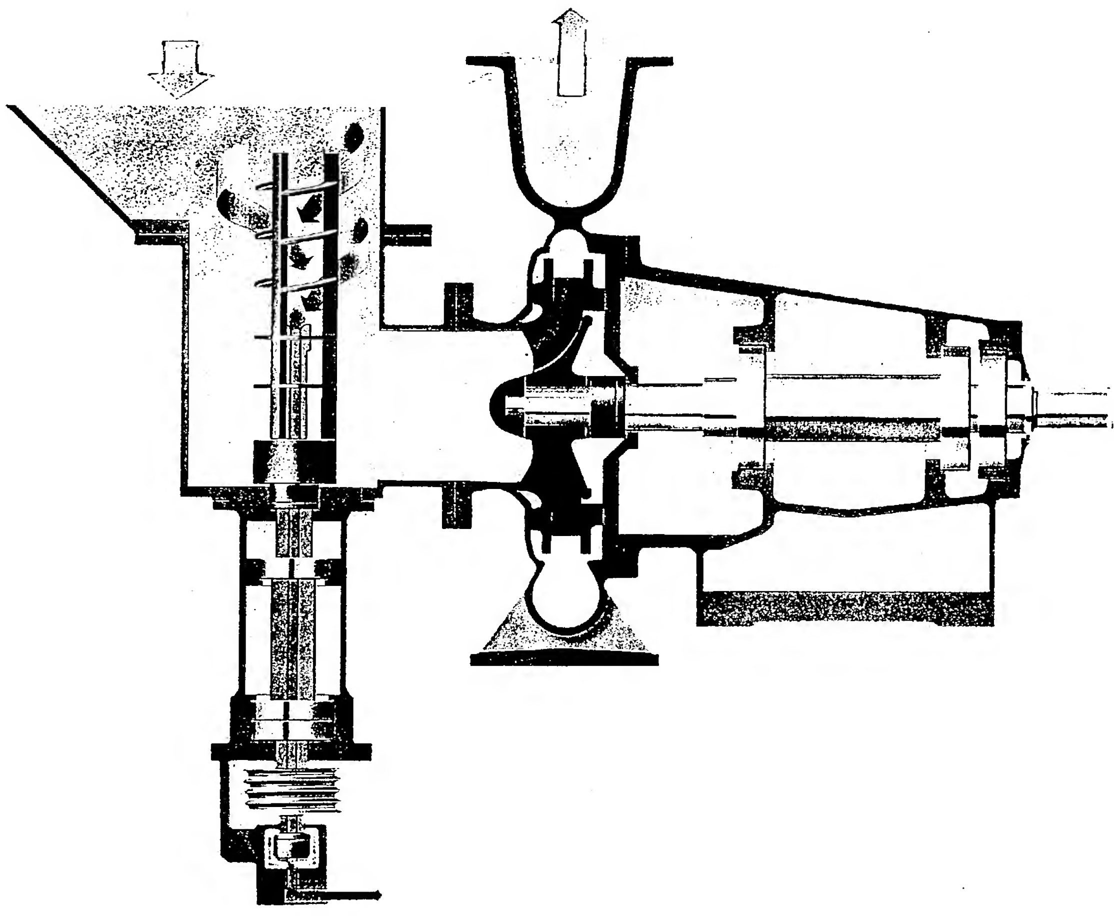

Figure 9-55. Medium consistency pump (Andritz).

(Warren Pumps

storage tank at a given stage of the process, a degree of blending can be achieved by filling the tanks in series and pumping out in a parallel configuration. In a mill utilizing medium-consistency technology, some blending can be achieved by employing an over-size pump for the storage tank discharge and returning a portion of the discharge flow back to the top of the same storage tank, thus intermixing pulp from two production periods.

9.9 PREPARING PULP FOR SHIPMENT

In integrated mills, pulp is usually stored at 10 – 14% consistency before use on the paper machine. For non-integrated operations, the pulp must be further dewatered to decrease transportation costs. If the transport distance is small, the pulp may be handled as a high-consistency "crumb", or most commonly in "wetlap" form. Occasionally, the web from a vacuum filter is simply carried on a felt through a series of roll presses to raise the consistency to 40 – 45%, and is then either wound into rolls or cut into sheets for shipment. A complete wetlap system utilizing a double-wire press for initial dewatering and pressing is shown in Figure 9-60.

In most instances, it is necessary to dry the web prior to shipment. Pulp deliveries are commonly made at 90 – 95% air dry (equivalent to 81 - 86% oven dry) in the form of baled sheets. The dominant method, developed from the paper machine, utilizes a sheet-forming wet end (usually a fourdrinier, but sometimes a cylinder former), a press section, a drying section, and usually an on-machine slitting and sheet-cutting operation. The operations of forming, pressing, and steam-cylinder drying will be discussed under "Paper Manufacture" in Chapters 16 and 17. Two other methods of drying are more often used for pulp, and these will be discussed here.

Air Float Dryer

An exterior view of an air float dryer showing the position of the fans is provided in Figure 9-61. The principle of operation is illustrated in Figures 9-62 through 9-64. The pulp web is carried in a number of passes through a chamber in which heated air is used both for drying and for supporting the web. Capital and operating costs are similar to the steam cylinder system, but most pulp producers favor the air float dryer because it is easier to operate and maintain.

In the earlier models of the air dryer, the pulp web is carried on mechanical conveyors and hot air is

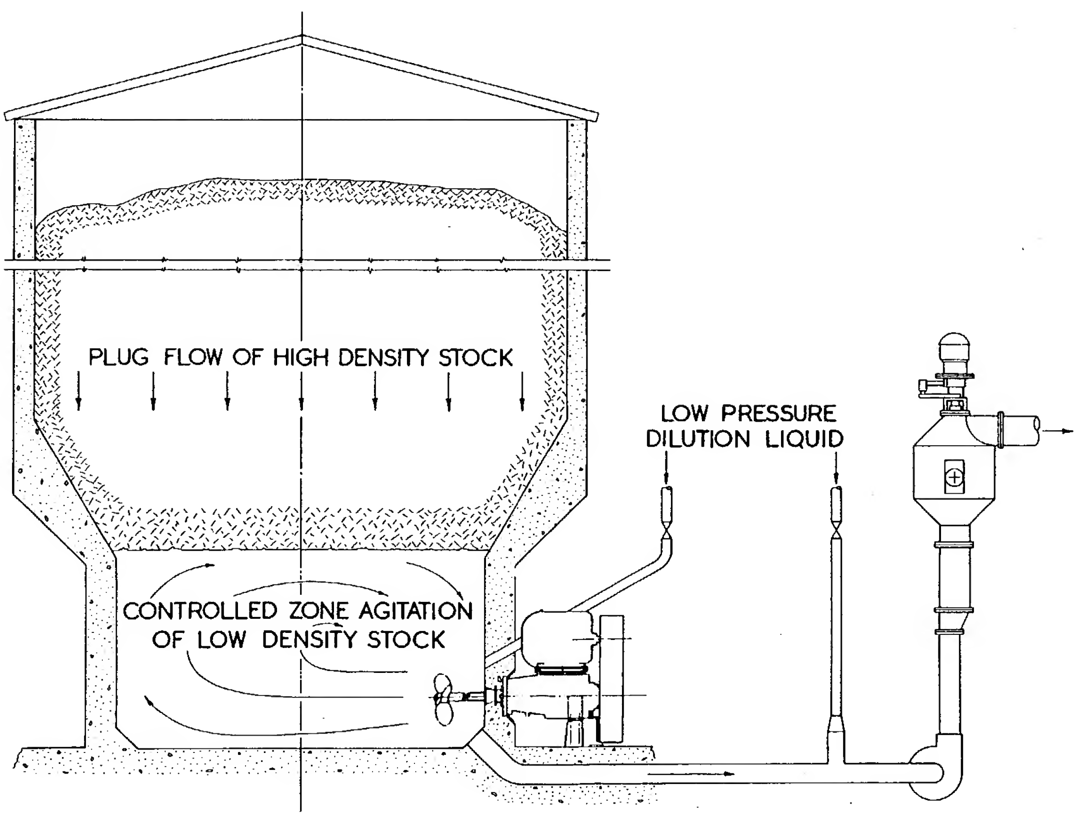

Figure 9-56. High density storage system illustrating zone agitation in the pump out section (Greey Mixing Equipment Ltd.)

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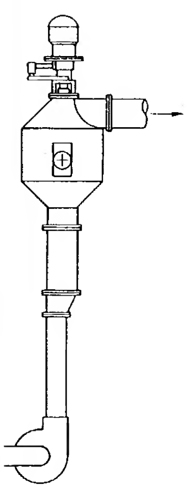

on (Greey Mixing

blown between the passes. The later designs incorporate true air impingement above and below the web; this principle provides much higher evaporation rates and eliminates the mechanical conveyor. Typically, the pulp web enters at the top, makes a number of horizontal passes turning around rollers at each end, and leaves at the bottom of the dryer at the opposite end. The fresh makeup air, which has been preheated in the economizer section (utilizing waste heat from the exhaust air) enters the bottom of the dryer. The air is circulated several times by means of numerous fans on both sides of the dryer and eventually exits at the top through the air-to-air heat exchanger of the economizer unit. On each pass, the air is heated by a steam coil and pumped through the blow boxes where the air jets issue from "eyelid openings" in the top and bottom to impinge on the pulp web.

The earlier models utilize a threading table at the entrance to the dryer for attaching the tail (a 6- to 10-inch wide continuous strip of pulp) to the "kite" (a large piece of cotton with pockets to pick up air) during startup of the drying operation. The newer units utilize an automatic system for carrying the tail through the dryer consisting of twin bands or a folded tape running beside the normal position of the pulp web at the operating side of the dryer.

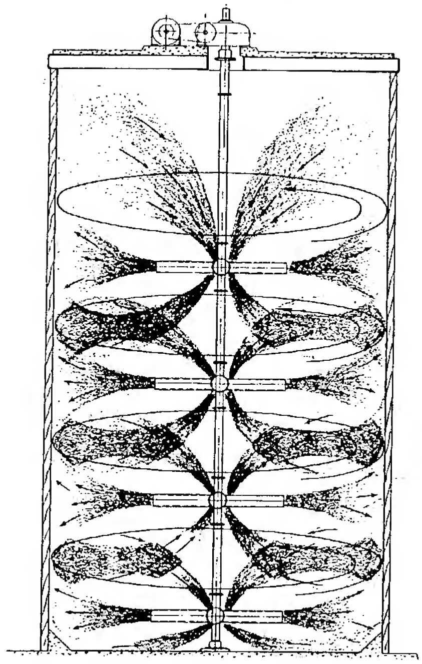

FIGURE 9-57. The Cowan stock agitator takes material from the center of the tank and distributes it to the periphery (S.W. Hooper Corp.).

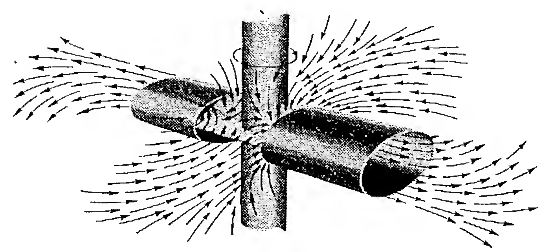

FIGURE 9-58. Illustrating the principle of the Cowan stock agitator (S.W. Hooper Corp.).

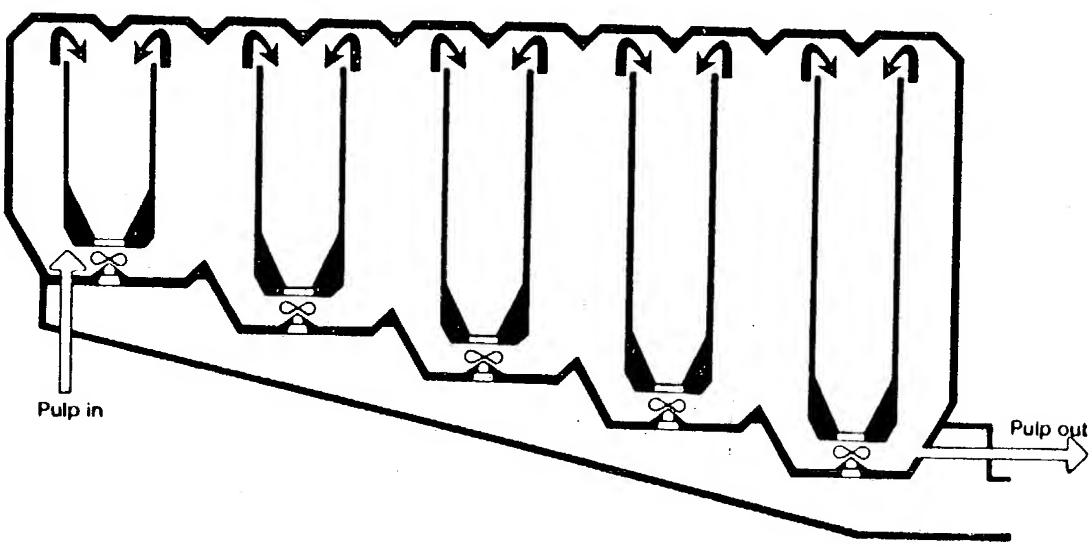

FIGURE 9-59. Low-consistency multichannel stock blending chest (Varkaus Paper Mill).

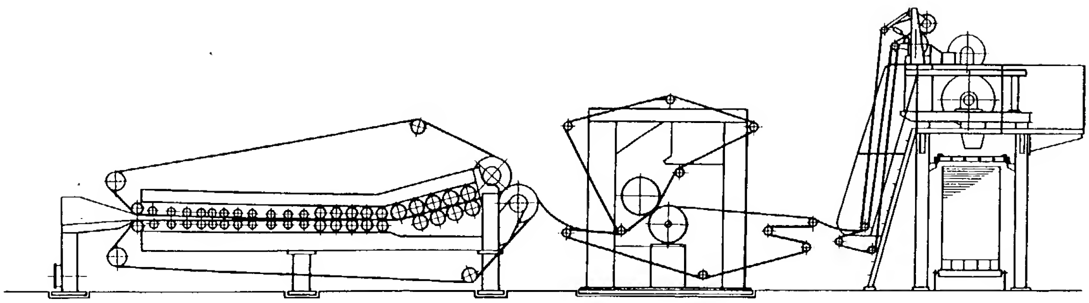

FIGURE 9-60. This wet-lap machine utilizes a double-wire press for initial dewatering of the stock suspension to achieve a consistency of up to 40% bone dry. The dryness is raised to 48 - 50% bone-dry by means of a heavy-duty press. The pulp web is then slit and cut into sheets by a rotating knife drum. The sheets drop onto a pallet. (Andritz)

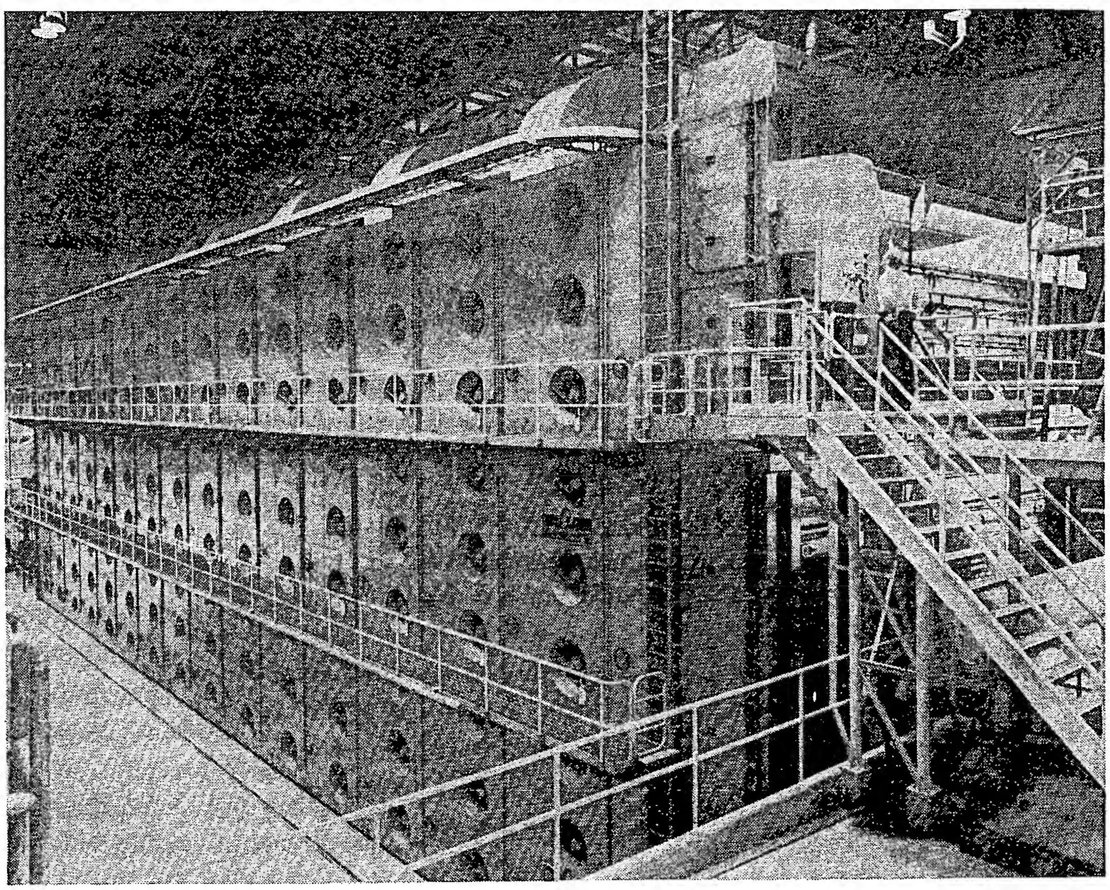

FIGURE 9-61. Airborne pulp dryer (ABB Flakt Canada Ltd.).

Sheet tension in the drying unit is controlled by nip and dance rolls at the entrance and exit. The turning rolls at the end of each pass are driven during threading, but turn free when the full-width web is in the dryer.

Criteria of Performance and Operating Variables

Two factors are of paramount importance when considering the relative performance of any pulp dryer: evaporation rate (a measure of capacity) and heat economy (a measure of energy efficiency). Typical units of measurement for these criteria applied to an air dryer are:

Area Evaporation Rate	lb water evap/sq ft/hr
Steam Economy	lb steam/lb water evap

Typical values of area evaporation rate are 0.9 to 1.0 for the older, mechanically-conveyed pulp dryer and 1.7 to 1.8 for the air impingement dryer. Steam economy can vary from as low as 1.2 to as high as 1.7. The main variables that affect these criteria are summarized in Table 9-6.

Generally, higher evaporation rates can be achieved when water is near the surface of the sheet, as with low-weight sheets at high moisture content. Of course, in terms of overall water removal, it is economically attractive to remove as much water as possible mechanically (by pressing) before applying evaporative drying.

Cutter and Layboy

The sheet from the dryer is typically conveyed to a series of slitters which cut the sheet to width, then a rotating fly knife cuts the sheets to length. The cut sheets are conveyed on tapes to the layboy boxes where they are stacked on the layboy table. A hydraulic system lowers the table as the stacks get higher. When the stacks are the correct weight, layboy "fingers" come out to support the sheets while the table lowers and discharges to a conveyor. The stacks of sheets are then conveyed to the finishing area where the stacks are weighed, compressed into bales, wrapped, wired, and labelled. Refer to Figure 9-65.

Flash Drying

Flash drying refers to the process where pressed pulp is first "fluffed" (i.e., the compressed mat is separated into fibers, thus greatly increasing the exposed surface area) and then injected into a stream of hot gases. The high-temperature heat of the gas stream causes the moisture to flash into vapor. A representative system is illustrated in Figure 9-66. The dried pulp product may be compressed directly into a bale, or into smaller pieces which are then formed into a bale (Figure 9-67).

Flash drying is attractive because of lower capital cost and less space requirement, even though operating costs may be comparatively higher. Some quality problems were experienced with flash drying systems of the late 1960's and early 1970's, primarily loss of brightness and formation of hard "pills" or "nodules" that were difficult to separate. Efficient operation of the fluffer was found to be the critical factor, since good separation and large specific surface allow the evaporation to take place more rapidly and at lower temperature.

A variation of flash drying is embodied in the so-called "steam dryer", where fluffed pulp is dried in a medium of slightly superheated low-pressure steam rather than in hot air (15). Heat is transferred to the pulp and transport steam by indirectly condensing higher-pressure steam. The water evaporated from the pulp is removed from the system as low-pressure steam suitable for process use in the pulp or paper mill. It is claimed that net heat consumption can be as low as one-fourth of that used in a conventional drying system.

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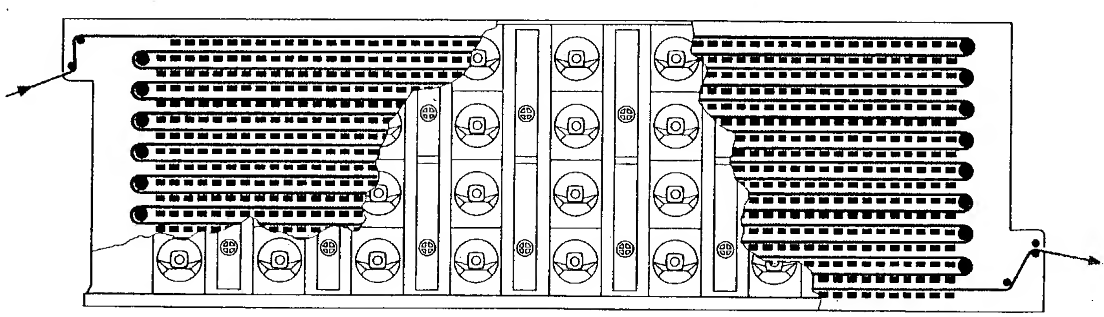

FIGURE 9-62. The pulp web moves over the dryer decks via turning rolls at the end sections (ABB Flakt Inc.).

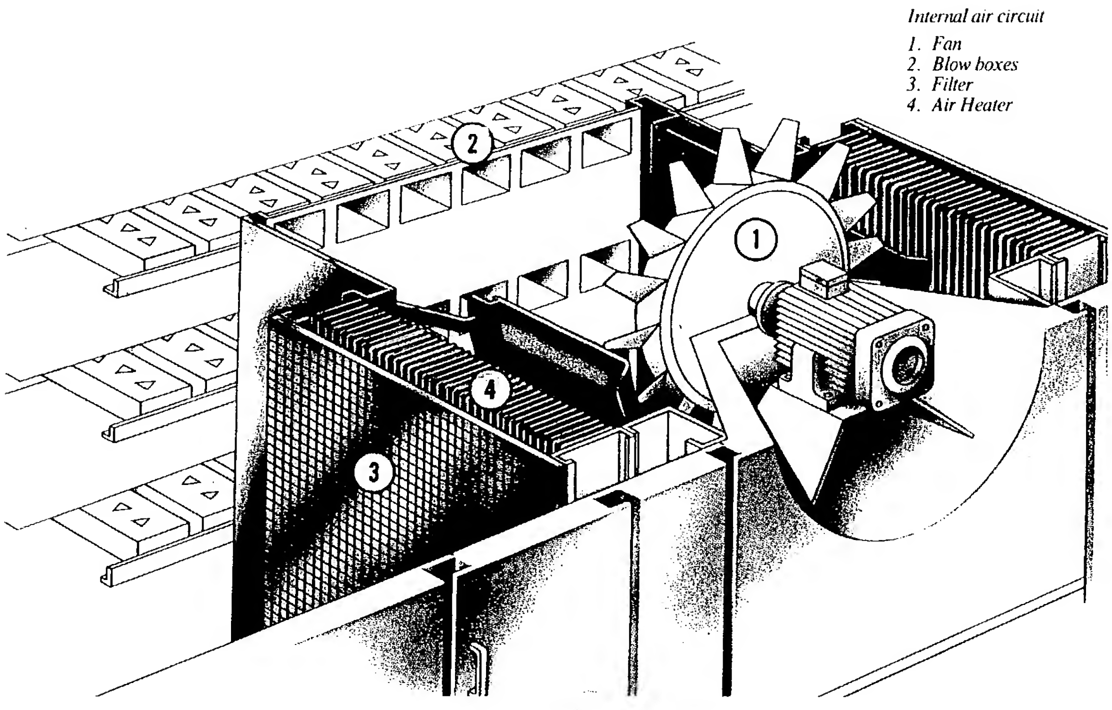

FIGURE 9-63. Longitudinally, the airborne dryer is composed of intermediate sections with steam coils for heating and fans for distributing the air to the blow boxes (ABB Flakt Inc.).

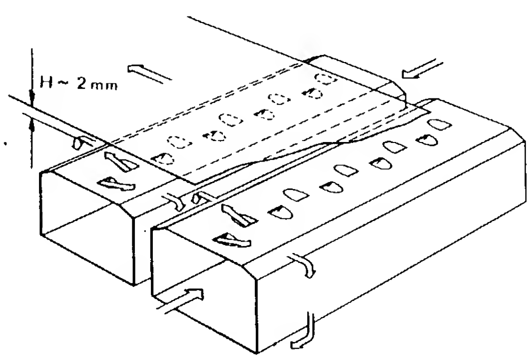

FIGURE 9-64. The air impingement system lifts the web clear of the deck and locates it at a fixed height.

TABLE 9-6. Variables that affect evaporation rate and steam economy.

Factors which favor high evaporation rate:
- low weight sheet (greater surface area)
- high ingoing sheet moisture
- high outgoing sheet moisture
- high air temperatures (high steam pressure in heaters)
- high rate of makeup air (low humidity in exhaust air)
- low stock pH

Factors which favor low steam economy:
- low rate of makeup air (high humidity in exhaust air)
- properly designed and maintained economizer
- proper balance between supply and exhaust air flows (i.e., minimize infiltration air and out-leakage of hot air)

(3) CROTOGINO, R.H., POIRIER, N.A. and TRINH, D.T. **The Principles of Pulp Washing** *Tappi Journal* (June 1987)
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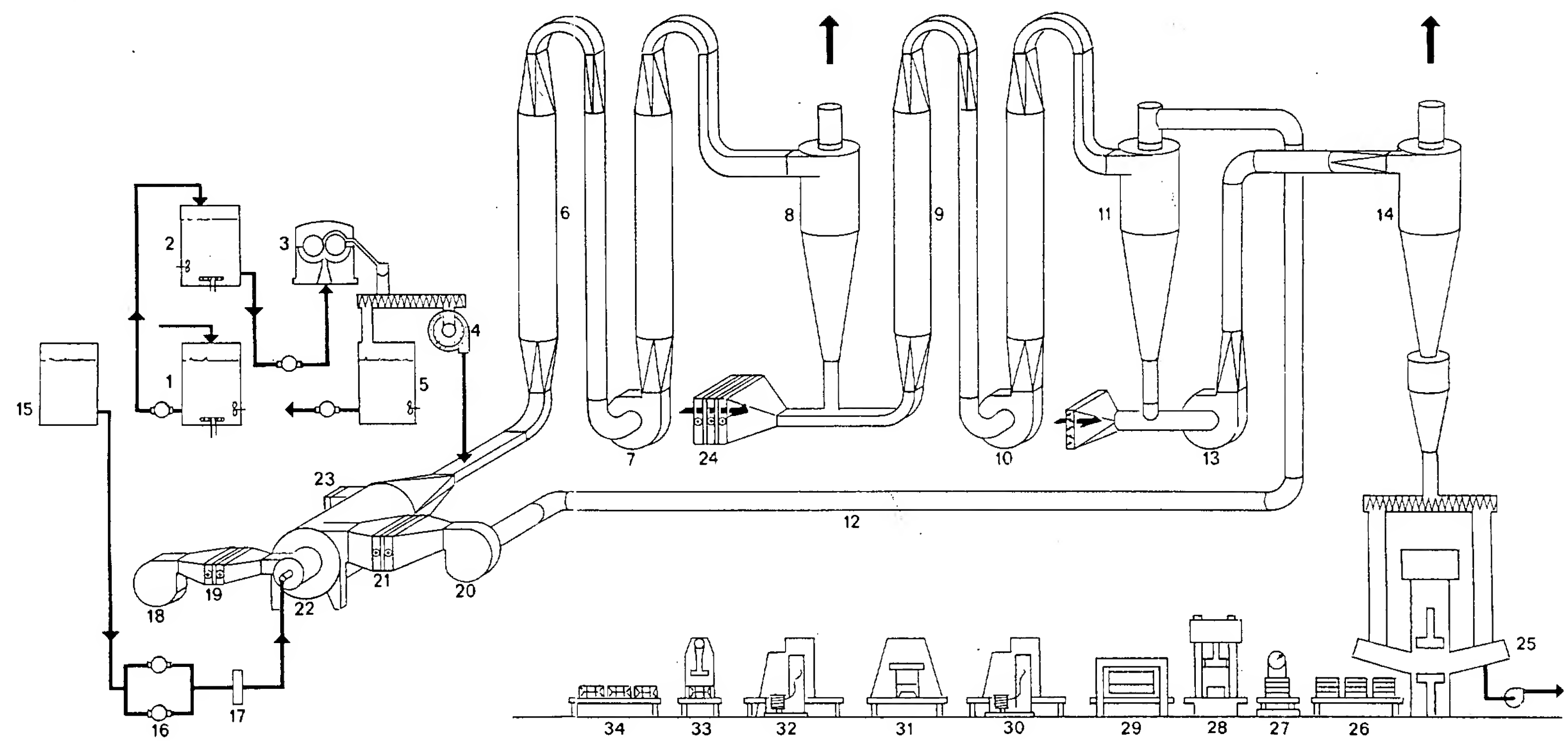

1. Incoming stock chest with temperature control
2. Equalising tank and consistency control
3. Dewatering press
4. Fluffer
5. Repulping tank
6. 1st stage, drying towers
7. 1st stage, drying air fan
8. 1st stage, cyclone
9. 2nd stage, drying towers
10. 2nd stage, drying air fan
11. 2nd stage, cyclone
12. Return air duct
13. Cooling stage fan
14. Cooling stage cyclone
15. Oil tank
16. Oil pump
17. Oil heater
18. Combustion air fan
19. Combustion air heater (optional)
20. Dilution air fan
21. Dilution air heater (optional)
22. Air heater for 1st stage
23. Fresh air damper
24. Air heater for 2nd stage
25. Slab press
26. Transport table
27. Scale
28. Baling press
29. Wrapper
30. Tying machine
31. Folding machine
32. Tying machine
33. Marking machine
34. Pulp bales

FIGURE 9-66. Flow chart for the Flakt flash dryer.

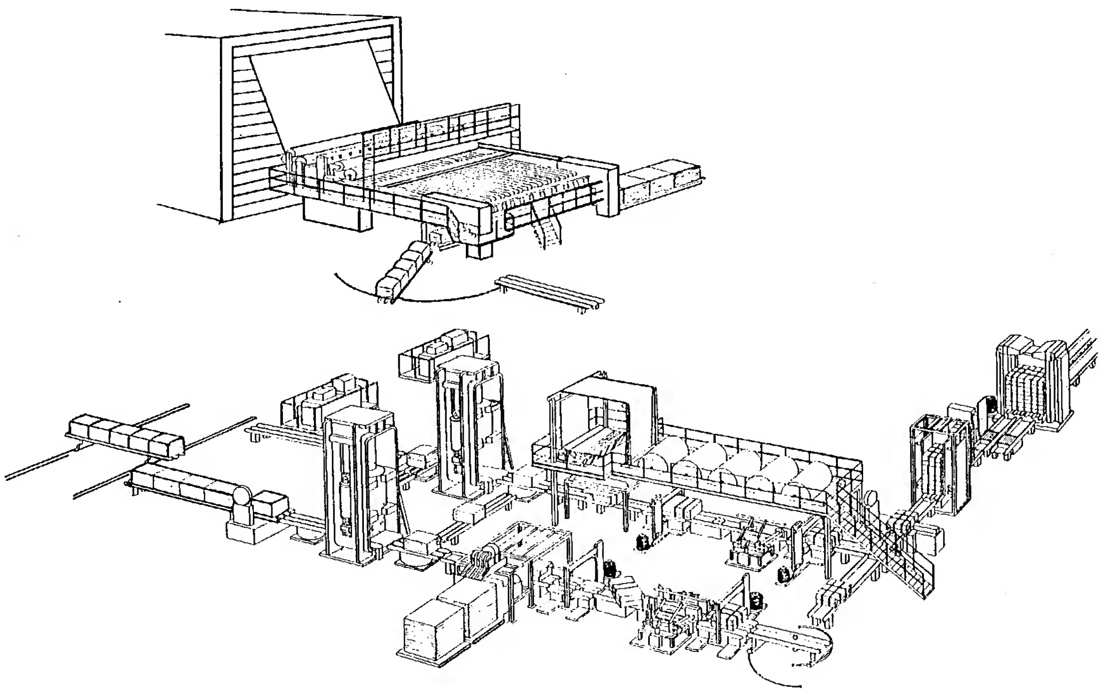

FIGURE 9-65. Pulp finishing line (Lamb).

(7) ATKEISON, C.A. **How to Achieve the Best Operation from Free-Discharge-Type Screens** *Pulp & Paper* (March 1979)

(8) NELSON, G.L. **The Screening Index: A Better Index for Screening Performance** *TAPPI 64*:5:133 (May 1981)

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(11) BLISS, T.L. **Stock Preparation, Chapter 6 - Cleaning (Volume 6, Pulp & Paper Manufacture)** Joint Textbook Committee, 1992

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(13) GULLICHSEN, J., et al **Medium Consistency Technology: Storage Dischargers and Centrifugal Pumps** *TAPPI 64*:9:113-116 (September 1981)

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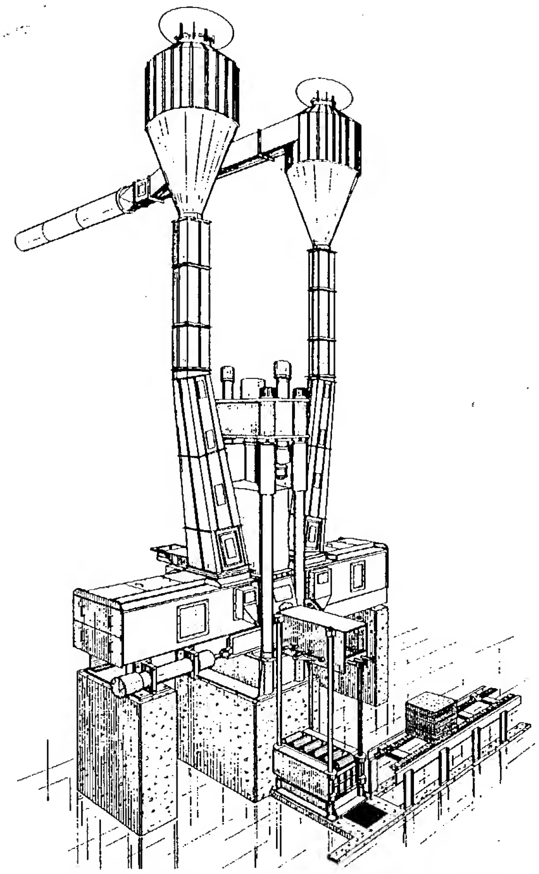

FIGURE 9-67. Vertical sheet former used in conjunction with D&S flash drying system (Vickers Canada).

Chapter 14 Secondary Fiber

Secondary fiber is defined as any fibrous material that has already undergone a manufacturing process and is being recycled as the raw material for another manufactured product. Strictly speaking, broke from the dry end of the paper machine, finishing room trimmings, and repulped rolls could be considered as secondary fiber; but in practice, internal recycling is not included as part of secondary fiber utilization.

Secondary fiber utilization is currently increasing at a rapid pace in North America. The driving force is governmental legislation which seeks to reduce landfill loadings and lessen dependency on forest resources by mandating minimum secondary fiber content levels for certain paper grades, notably newsprint. Traditionally, the supply of waste paper has been market-driven; but recently the emphasis has been on source separation, where paper and other recyclables are often collected irrespective of market demand. While significant imbalances in supply and demand have occurred in the past, the present over-supply of certain wastepaper grades (e.g., old newspapers) is large by historic standards. It now appears that enough new recycling capacity is being brought on line in the early 1990's to return to a demand-driven marketplace. In the meantime, excess wastepaper is being sold at bargain prices in the overseas market.

Secondary fiber plants are usually located in areas of high population density, where a dependable supply of waste material can be more easily collected and transported. It is generally less economical to gather materials outside a fifty-mile radius of the mill site, due to high transportation costs for the bulky wastepaper bales. However, it can be worthwhile to bring in wastepaper from considerable distances when there are significant price differentials.

Wastepaper Grades

Five basic grades of wastepaper are defined by the U.S. Dept. of Commerce, and these definitions are generally accepted by the paper industry:

- **Mixed Paper.** Paper of varied quality; included in this category are office waste, boxboard cuttings and mill wrappers.
- **Old Newspapers (ONP).**
- **Old Corrugated Containers (OCC).**
- **Pulp Substitutes.** Mainly consisting of unprinted paper and board that has not been coated or adulterated in any way; included in this category are tabulating cards, white and semibleached sheets, cuttings, shavings or trim.
- **High-grade Deinked.**

The Paper Stock Institute further subdivides these grades into 80 definitive groups.

Pulp substitute grades command top prices because they can be utilized directly in the papermaking process for certain products. (These grades have always been fully recovered for recycle.) Other wastepapers must be cleaned up in the secondary fiber pulping system to remove contaminants. Separation and/or dispersion of such contraries as plastic laminates, adhesives, glues, waxes, etc. is sufficient for secondary pulps that are used for the inner plies of a multi-ply paperboard or for corrugating medium. But for printing grades, more selective removal of contaminants, including deinking, is necessary to prepare a suitable papermaking stock.

The relative usages by wastepaper grade are shown in Table 14-1 for 1977 and 1988. OCC accounts for about 50% of the total. Approximately 75% of all secondary fiber in North America is presently used for multiply paperboard and corrugating medium production, but an increasing proportion will be deinked and utilized for newsprint and other printing grades over the next decade.

14.1 WASTEPAPER PROCUREMENT

In order for wastepaper to be efficiently utilized as secondary fiber, it is necessary that the collected material be sorted and classified into appropriate quality grades. Sorting may occur at the source or be carried out by the collecting agency. Where many sources are involved, a dealer or broker usually assumes the tasks of collecting, sorting, baling, and supplying to the mill. Normally, the utilizing mill does not sort the incoming wastepaper, but monitors the material to ensure that minimum quality standards are being met.

Wastepaper sources are generally categorized as pre-consumer or post-consumer. Pre-consumer

Table 14-1. Relative Wastepaper Usage (API Data).

	1977	1988
Mixed Paper	19%	11%
ONP	16%	16%
OCC	43%	49%
Pulp Substitutes	15%	15%
High-grade Deinked	7%	9%

sources are converting plants and printers where wastepaper, in the form of cull rolls, clippings, off-quality product, or over-issue, is generally clean and well sorted. Typical post-consumer sources are homes, offices, and retail outlets from which the waste must be collected, sorted and baled. Wastepaper from post-consumer sources is considered less desirable because it is relatively less sorted and higher in contamination.

Wastepaper prices around the world are mainly determined by demand, and also to some extent by the ease with which supplies can be obtained (1). The relationship is hard to quantify and varies with the grade of wastepaper. When shortages arise, mills are usually prepared to pay higher prices to generate additional supplies. Wastepaper prices are highly cyclical, and their main characteristic is instability. Except for the highest quality grades, wastepaper prices have been depressed in recent years because of excess supply.

Wastepaper recovery methods have changed markedly in the United States over the past few years, especially for ONP and OCC. About 60% of the ONP now comes from curbside collection and other city-operated recycling programs. Municipal governments, not wastepaper dealers, are controlling the flow of ONP into the mills. In many instances, the wastepaper dealer is being bypassed as the municipality sorts, bales, and sells the ONP directly to the mills.

A similar pattern can be seen for OCC. Approximately 60% of this recycled material now goes directly from chain stores to the mills, many of whom have signed long-term contracts to take all the available OCC. Municipal curbside collection may prove to be another important source of OCC.

Raw Material Storage and Handling

Bales of wastepaper are typically delivered to the mill by truck or rail, and are inspected during off-loading to insure that they conform to mill requirements. It is good warehousing practice to segregate both by grade and by specific supplier, so that any quality problems can be traced back to the secondary fiber source. Outside storage should be avoided, if possible, because exposure to sunlight and weathering causes deterioration in pulp properties. Also, relatively "fresh" secondary fiber is more easily deinked than older stock. Generally, it is desirable to operate a storage facility on a "first-in, first-out" basis.

14.2 DEGREE OF RECYCLING

Two primary indices are used to compare the level of recycling in various countries (2). Recovery rate is the amount of wastepaper recovered for reuse compared with paper consumed. Utilization rate is the amount of secondary fiber used in paper/board production compared with the total fiber used. The recovery rate in the United States has been setting new records in recent years and reached 33% in 1990. By contrast, such countries as Japan and Taiwan without a forest resource base have long had recovery rates approaching 50%. The average recovery rate in Europe is about 30%, and in Canada about 25%.

Secondary fiber utilization in the United States is about 25% and is climbing slowly. In Japan, it is about 50%, and the average utilization rate in Europe is about 40%. In the leading paper exporting countries, the utilization rate is understandably less; for example, about 10% in Sweden and Canada.

It is generally considered that 50% represents a practical maximum for an overall utilization rate . Significant losses of both fiber substance and strength occur during each recycling. (Some investigators have suggested that a fiber can be recycled only four times before the loss in quality becomes too great for effective reuse.) At a sustained 50% level, it is apparent that half of the material being recycled at any time has already been through one or more previous cycles.

The effects of multiple recycling operations on fiber characteristics and sheet properties have been investigated to some extent in the laboratory. Most of these studies were undertaken in the decade from the late 1960's to the late 1970's (3). However, it is not clear how well a laboratory can simulate the fiber attrition that takes place from actual paper usage and recycle. Figure 14-1 summarizes results from one study on a never-dried unbleached softwood kraft pulp (3) that had been refined down to 285 CSF. Over the course of four recycles, the fines content increased from 16% to 35% and caused a severe reduction in stock drainage. Presumably, for the test handsheets, fines were removed after each recycle to maintain the same freeness level. As expected, the fibers exhibit progressively lower strength and bonding potential; the initial increase in tear is due to the effect of drying on fiber stiffness.

Figure 14-2 illustrates the relative effects of repeated recycling of newsprint on individual fiber

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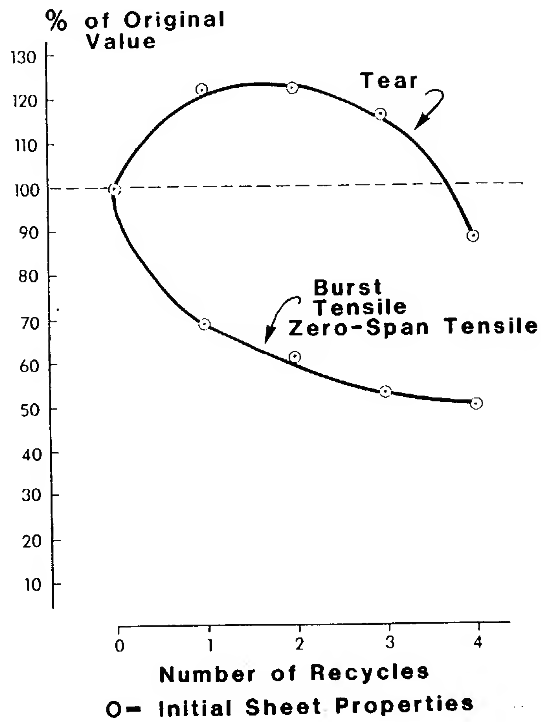

FIGURE 14-1. Effect of multiple recycling on strength properties of unbleached kraft pulp handsheets.

strength and on the bonding strength between fibers. In this instance, both strength indices decrease, but the bonding between fibers shows the more dramatic loss. With each drying and slushing cycle, the fibers become less flexible and less permeable to water, and therefore do not conform as well as virgin fibers. Cumulative loss of hemicelluloses from the fiber surfaces also contributes toward reduced bonding.

It should be emphasized that various fibers may react in different ways to recycling. Investigative findings for one specific type of fiber cannot necessarily be applied to another type of pulp.

14.3 REPULPING OF WASTEPAPER

Wastepaper bales are conveyed to a pulper where the secondary fiber is dispersed into a wet pulp slurry. Depending on the papermaking requirements, the pulper may also cause ink and coating particles to separate from the fibers. Such variables as temperature, consistency, retention time, and chemistry must be controlled to optimize the operation.

At the heart of the repulping operation is the pulper itself. The most common design, illustrated schematically in Figure 14-3, is the low-consistency pulper with ragger and junker, which is usually run

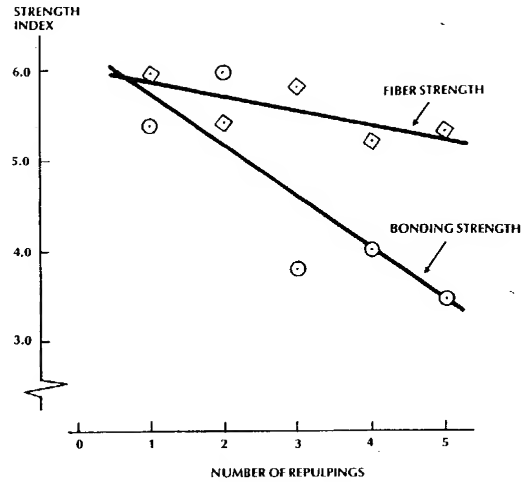

FIGURE 14-2. Effect of multiple recycling on fiber and bonding strengths of newsprint (P. Howarth).

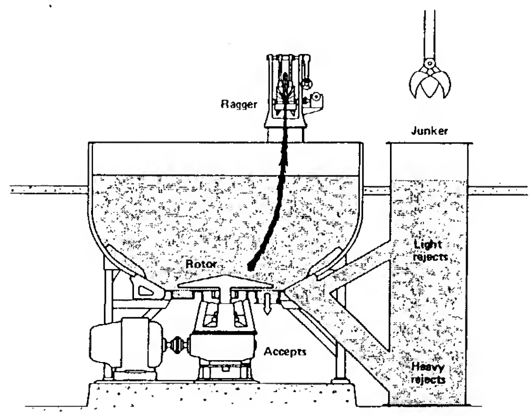

FIGURE 14-3. Schematic of continuous pulper with ragger and junker (Lodding, Div. of Thermo Electron).

at 5-8% consistency, and may be operated in either continuous or batch mode. Strings, wires and rags are continuously withdrawn from the stock as a "debris rope". Initially, a few "primer wires" are rotated in the stock to start the rope, after which the rope builds on itself. Heavy objects are thrown into a recess at the side of the pulper by centrifugal force; this material is usually removed from the "junking tower" by a bucket elevator or grapple.

The high-consistency pulper (as introduced and illustrated in Section 13.1) has also been applied to secondary pulping systems. It has the advantage of maintaining contaminants, such as plastics and wet

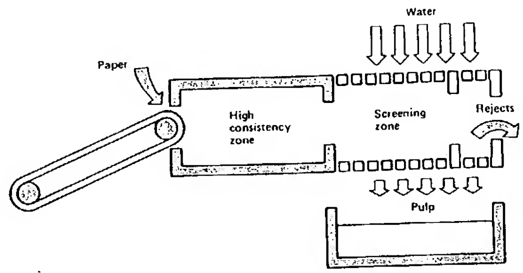

FIGURE 14-4. Schematic of drum-type pulper (Ahlstrom).

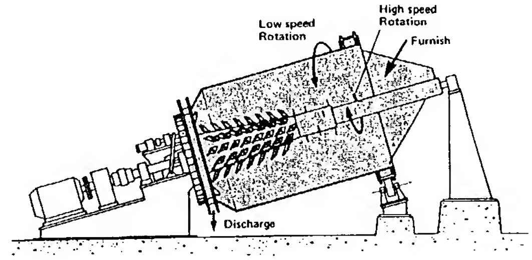

FIGURE 14-5. Betonniere high-consistency pulper (Lamort-Aikawa-Lodding).

strength flakes, in a larger form to facilitate their later removal; it also provides better ink removal and has a relatively gentle action on the fibers. This type of pulper must be operated batch-wise, but batch times are generally shorter than for low-consistency pulpers.

The drum pulper, illustrated schematically in Figure 14-4, consists of a slowly rotating sectionalized horizontal drum that is inclined toward the discharge end. Bales of wastepaper (which have previously been dewired and broken apart) and water enter the feed end where the drum rotation produces a tumbling action which causes the bales to break down into individual fibers. The pulp at 15-20% consistency then moves from the pulping zone into the screening zone where showers wash the fibers through perforations while contaminants are retained within the drum and are discharged at the end. Although its capital cost is relatively high, the drum pulper requires less energy than other designs and provides a gentle pulping action.

A special design of pulper, utilizing both a high-speed disintegrating rotor and low-speed drum rotation, is illustrated in Figure 14-5. The Betonniere, which loosely translates into "cement mixer", is suitable for operation in the 35-45% consistency range. It is said to be effective for the most difficult furnishes, including wet-strength papers, but can be used for any application where a high consistency is required following pulping.

Many pulping systems also utilize a secondary in-line repulping device, one type of which is illustrated in Figure 14-6. In addition to more defibering, this equipment has the ability to further separate both heavy and light-floating trash. In-line units generally consist of a conical housing containing the rotating defibering element. The accepted stock passes through a perforated stainless steel plate that is positioned immediately behind the rotor and is collected in an annular channel. Depending on their design or function, secondary pulping devices may be designated as dispergers, fiberizers, or deflakers.

Other than equipment design and applied energy, the major variables affecting degree of defibering are stock temperature and consistency. In general, a higher temperature will facilitate defibering, while power requirements are reduced because of increased fluidity. Consistency should be maintained at the highest level that still gives good circulation.

A basic pulping system for relatively clean wastepaper stock is shown in Figure 14-7. The stock passes through the small-hole extraction plate of the pulper, then to a liquid cyclone for removal of small high-density contaminants, and finally through a fine screen. The screen rejects go through a deflaker or fiberizer to provide more complete fiber separation, and this stock is reclaimed through a secondary screening system back to the pulper.

Another pulping system which utilizes a side mounted low-consistency pulper and a secondary pulping device is well illustrated in Figure 14-8. This system features three stages of screening, and is said to be effective for wastepapers containing a high percentage of dirt.

14.4 CONTAMINANT REMOVAL

A prime objective in processing wastepaper stocks is to remove enough contaminants and/or upgrade

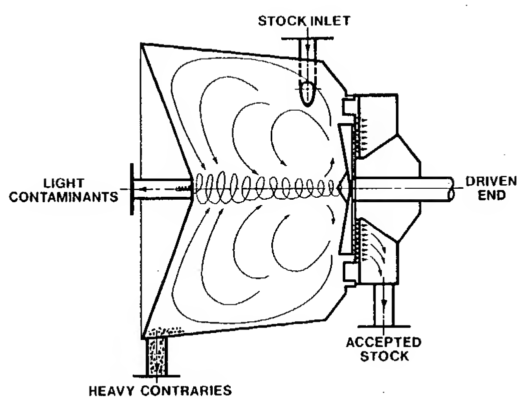

FIGURE 14-6. Secondary pulper for wastepaper processing (Escher-Wyss, Impco).

the material so that the secondary fiber is suitable to make the finished product within specifications. The major process steps that may be used are screening, cleaning, washing, bleaching, dispersion and deinking.

Even when stringent standards are applied to incoming wastepapers, contaminants cannot be totally avoided and must be dealt with in the process system. All extraneous constituents are considered contaminants, including dirt, rocks, sand, and tramp metal. Some of the more difficult product-related contaminants and their sources are listed in Table 14-2. In practice, such contaminants as glues, hot melts and latexes are lumped together into the category of "stickies" or "tackies".

As already noted, most of the primary pulping equipment and secondary in-line pulpers and/or deflakers have the ability to remove much of the gross contamination. Some are augmented with a so-called flotation purge system to help remove the lighter weight contaminants. Beyond this, all systems have suitable screens for removing oversize particles and centrifugal separators (forward and reverse cleaners) for removing all types of fine particle contamination. Each of the major suppliers of secondary pulping equipment specifies or recommends an assembly of screens and cleaners which is compatible with their own pulping equipment and with the requirements of a particular wastepaper furnish.

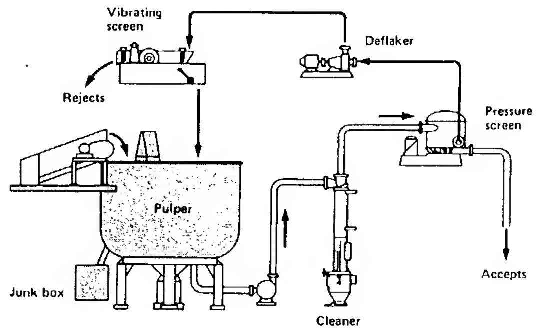

FIGURE 14-7. Simplified conventional pulping system for recycled fiber (Lodding, Div. Thermo Electron).

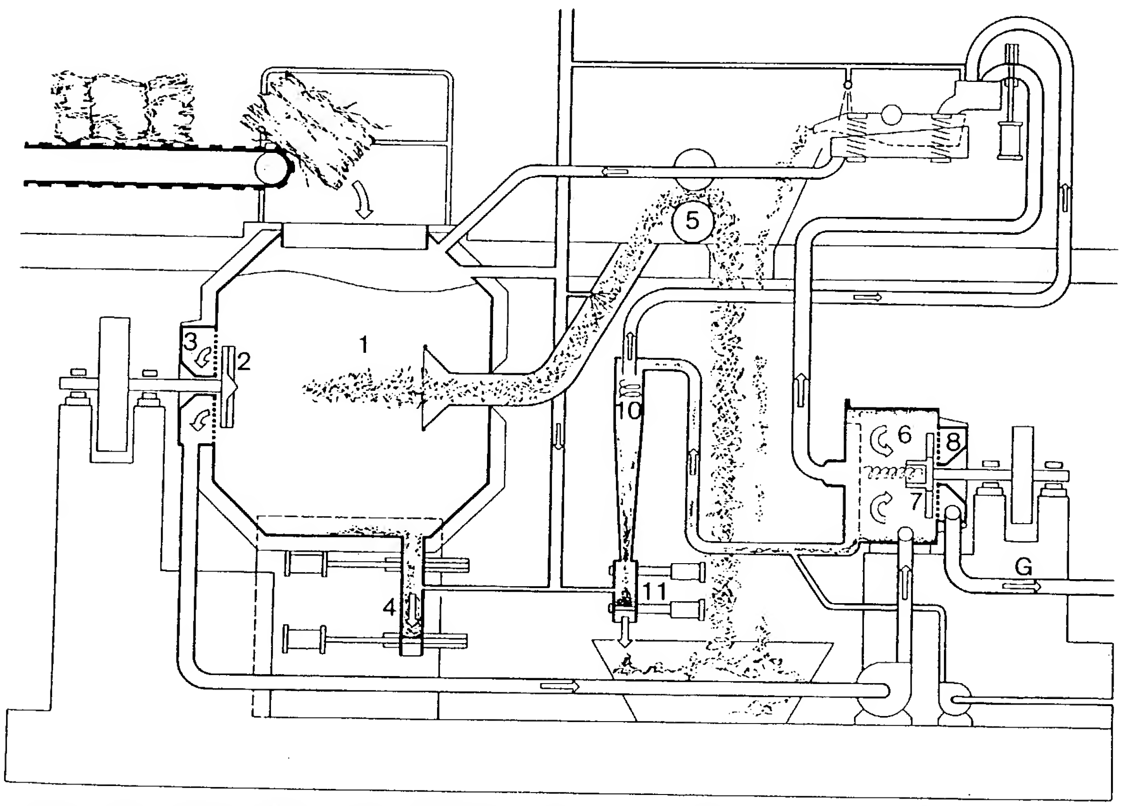

FIGURE 14-8. Functional diagram of Voith-Morden system for the pulping of unsorted, mixed wastepapers. (1) pulper, (2) impeller, (3) & (8) screen plate, (4) & (11) dirt trap, (5) ragger, (6) secondary pulper, (7) pulping assembly, (9) lightweight contraries screen, (10) forward cleaner.

TABLE 14-2. Common contaminants in wastepaper repulping systems.

Type of Contaminant	Typical Sources	In-Mill Problems
Hot Melts	Adhesives and coatings	Cannot be handled in conventional systems; fouls equipment; causes defects in products.
Polystyrene Foam	Blocks and beads used in packaging	Difficult to remove; sticks to rolls; causes sheet indentations and "pickouts".
Dense Plastic Chips (e.g., polystyrene)	Blister packs and see-through packages	Breaks into small pieces; hard to remove; causes "shiner" in product.
Wet Strength Resins	Laminated paper products, tramp material	Slows down pulper process; causes product defects.
Latex	Adhesives and coatings; flying pasters; rubber bands	Difficult to remove; causes product defects.
Pressure Sensitives	Roll splices; case seals; miscellaneous	Sticks to fabrics and felts; causes sheet defects and web breaks.
Waxes	Coatings and laminates	Difficult to disperse; fouls equipment and degrades products.
Asphalt	Laminated products	Agglomerates in pulper; sticks to fabrics; causes black spots in products.
Foreign Fibers	Vegetable and synthetic rope fibers	Causes product defects and web breaks.

A dispersion system is sometimes incorporated into a secondary pulping system to control certain stickies. The objective is to disperse the contaminants thoroughly over the surfaces of the fibers and thereby nullify any adverse effects. Both hot and cold systems are available; the hot systems generally yield a cleaner appearance, but the cold systems are adequate for stocks used as filler plies in multiply products. Figure 14-9 shows a modern dispersion system suitable for either atmospheric or pressurized operation. In this sequence, the incoming dilute stock is thickened to 35% consistency by a two-stage screw press arrangement and fed through a plug screw (to prevent steam blow-back during pressurized operation) to a vertical shredder which fluffs up the stock. The fluffed pulp is then mixed with steam in a preheater before being fed to the disperser, a device similar in operation to a disc refiner.

Relatively elaborate systems are used to remove the more troublesome contaminants. These treatments include bleaching, deinking (to be discussed in the next section), hot melt extraction, and solvent extraction. However, some contaminants (e.g., vinyl acetates, polypropylene) have defied all efforts to effectively handle them in the wastepaper system, and they are best excluded from the furnish.

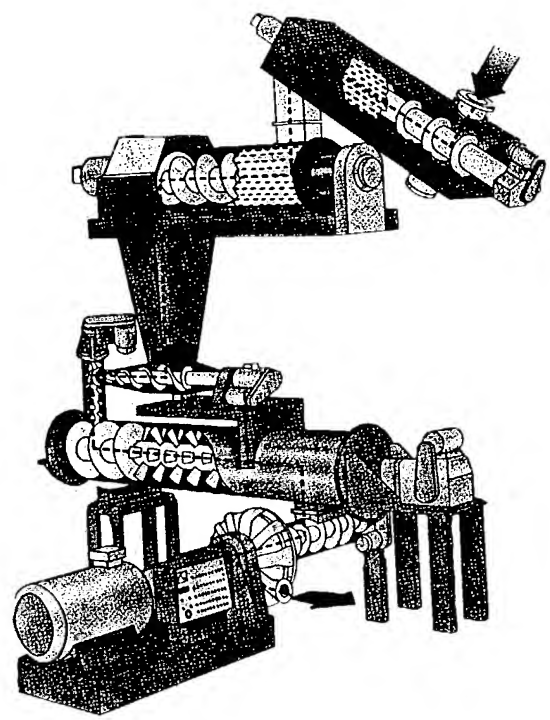

FIGURE 14-9. Dispersion system suitable for atmospheric or pressurized operation. (Krima, Cellwood Machinery).

14.5 DEINKING

Deinking of pulp fibers is essentially a laundering or cleaning process where the ink is considered to be the dirt. Chemicals, along with heat and mechanical

energy, are used during repulping to dislodge the ink particles from the fibers and disperse them in the stock suspension. The ink particles are then separated from the so-called "grey stock" by a series of washing or flotation steps, or by applying a hybrid process that utilizes both separation techniques.

The key chemicals used for stock deinking are surface active agents ("surfactants"), which affect the surface tension of liquids and solids. Typically, these agents are chemically modified mineral oils, where hydrophillic groups have been added to the molecular structures to make them partly soluble. Three specific types of surfactants are important in deinking applications:

- detergents—to remove ink from the fiber
- dispersants—to keep the ink particles dispersed and prevent re-deposition onto the fibers
- foaming agents—to reduce the surface tension of water and to promote foam formation

Other chemicals such as caustic soda, sodium silicate, and borax are also used to enhance the action of the surfactants.

Washing Process

In the washing process, detergents and dispersants are utilized in the pulper to remove the ink constituents from the fibers, break them down, and disperse them into very fine particles. The ink dispersion is subsequently separated from the pulp, typically by a multistage dilution/thickening washing sequence. A representative washing process is illustrated in Figure 14-10.

The separation of ink in the washing process corresponds to a stock thickening process, whether accomplished by washing equipment or by screens. If the ink particles are extremely small (less than 15 microns), the amount removed is theoretically proportional to the amount of water removed (Figure 14-11 and Table 14-3). In practice, the fiber network acts as a filter to reduce the actual removal efficiency.

The filtering effect during washing is minimized by operating at low consistency and by utilizing thickening equipment that does not involve mat formation, such as the sidehill thickener (Figure 14-12), slusher, or Celleco screen. An incoming consistency of 1.0 to 1.5% would be ideal because the filtering effect is low; however, older plants utilizing this consistency range had large space requirements. As a consequence, an incoming consistency of about 3% in conjunction with a countercurrent washing sequence is more common, but thorough reduction in particle size is more critical. Pulp is diluted with clarified water only ahead of the last washing stage.

Recently, washing machines, such as the double-nip thickener (Figure 14-13), have been developed that can thicken large volumes of low-consistency stock up to 8-12% consistency in a single stage. Equipment of this type operates in the manner of a low-retention papermachine wet end. The stock at low consistency is introduced via a headbox onto an endless fabric belt where water is removed by the action of the fabric as it moves rapidly around a turning roll.

Flotation Process

In the flotation process, chemicals are introduced during the repulping operation to promote flocculation of the ink particles and the formation of foam. The grey stock is subsequently aerated at low consistency (typically 0.8 to 1.2%) in a series of flotation cells, causing the light flocs of ink particles to rise to the surface where they are skimmed off. A representative flotation process is illustrated in Figure 14-14.

At the heart of the flotation process is the flotation cell, of which several designs are available (Figures 14-15 to 14-17). Here, air in the form of small bubbles is blended with the grey stock. The air bubbles become attached to ink and dirt particles, causing them to rise to the surface of the cell where they are removed as a dirt-laden layer of froth. Typically, 6 to 10 flotation cells in series are required for efficient ink removal depending on the level of dirt in the stock. The froth is subsequently cleaned in a secondary stage (usually two cells) to recover good fiber.

For reasons that are not clear, flotation deinking is far more effective when the wastepaper has a

TABLE 14-3. Theoretical ink removal.

Washer	Consistency, % Inlet	Consistency, % Discharge	Theoretical Ink Removal, % One-stage	Theoretical Ink Removal, % Three-stage	Dilution Water Required, gal/ton
Sidehill screen	0.8	3.0	74.0	98.2	26,740
Gravity decker	0.9	6.0	85.5	99.7	23,740
Inclined screw	3.0	10.0	72.2	97.8	6,950
Horizontal press	4.0	28.0	89.2	99.9	5,150

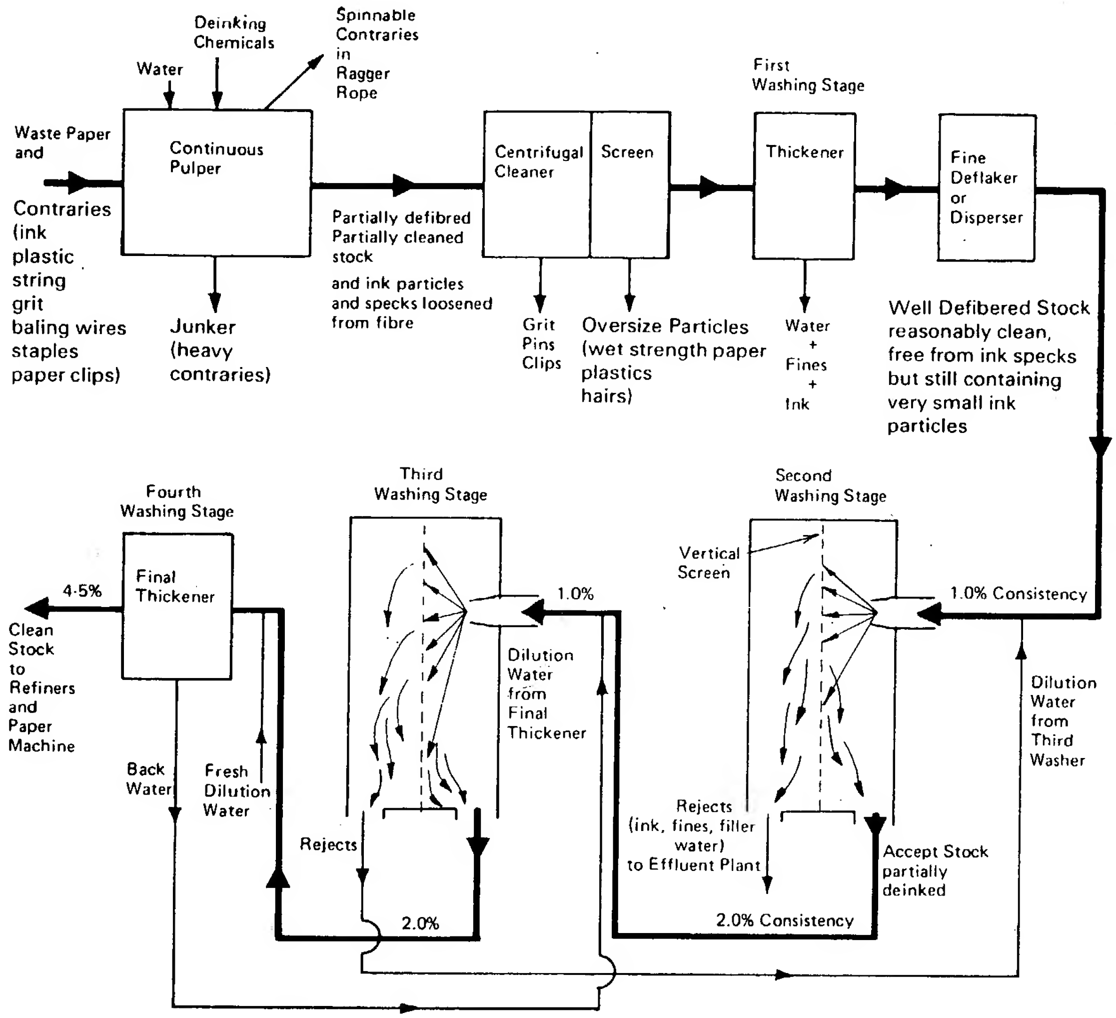

FIGURE 14-10. Deink wash plant using vertical screens (Celleco-type) and countercurrent wash water flow sequence.

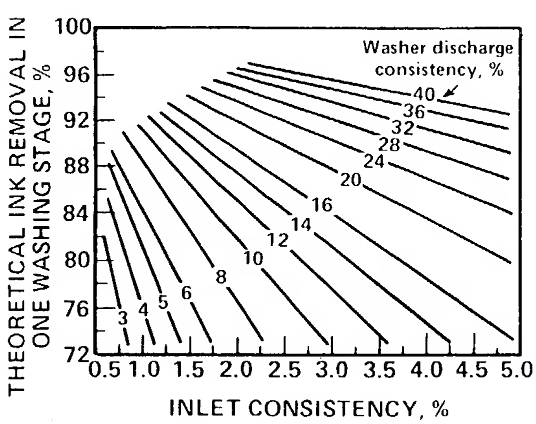

FIGURE 14-11. Theoretical ink removal in one washing stage as a function of washer inlet and discharge consistencies.

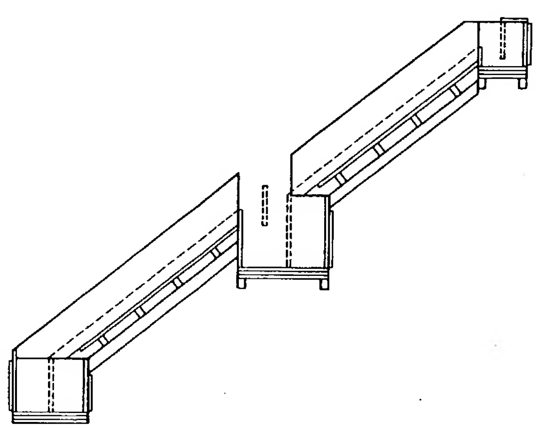

FIGURE 14-12. Two-stage sidehill screen/thickener.

significant ash content. A clay content of 8 to 10% is considered a minimum requirement, and 12 to 14% is preferable (5). The requisite level can usually be maintained by blending in coated waste with the wastepaper. Approximately 25 to 30% of the clay is removed with the flotation cell rejects.

The flotation method is generally favored in Europe and Japan. The washing method has traditionally been more popular in North America because of lower capital cost and lower space requirements. The flotation method is more selective in removing ink particles and therefore provides a significantly higher yield than the washing system. On the other hand, the washing process removes a high proportion of fiber fines and fillers along with the ink particles which has the effect of upgrading the pulp. Flotation-deinked stock requires little washing because the

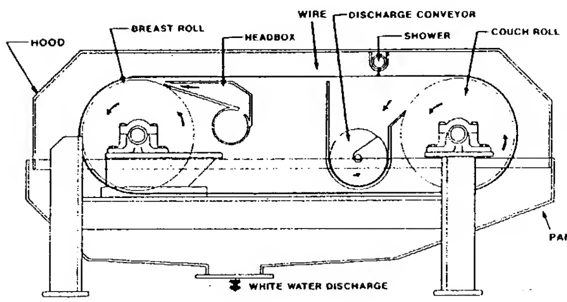

FIGURE 14-13. Double-Nip Thickener (Black-Clawson).

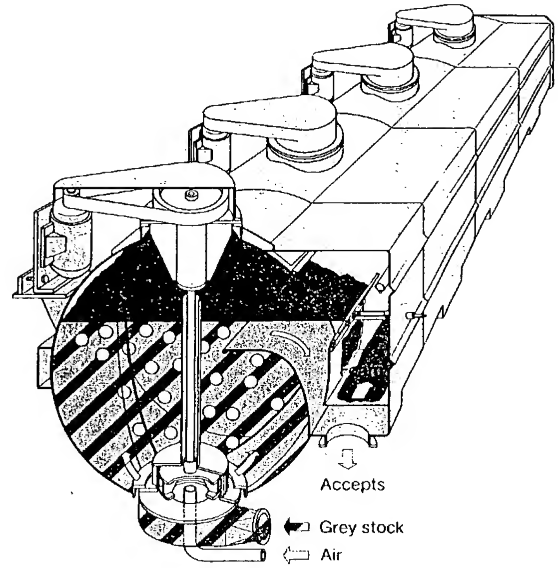

FIGURE 14-15. Voith flotation cell.

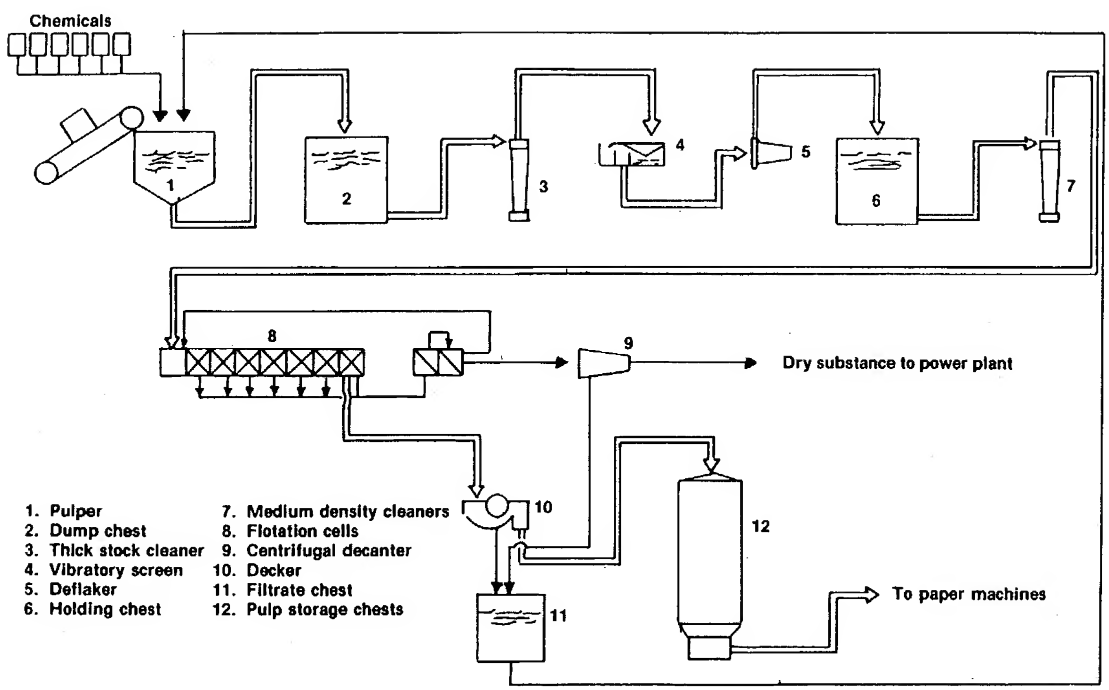

FIGURE 14-14. Representative flotation deinking process.

chemicals are concentrated in the withdrawn froth. Effluent treatment for the flotation process is usually simpler than for the washing process.

The size of the ink particles to be removed should be a primary basis for selecting the appropriate removal process. Inks that are amenable to being broken down during the repulping operation are more easily removed by the washing process than those that withstand treatment.

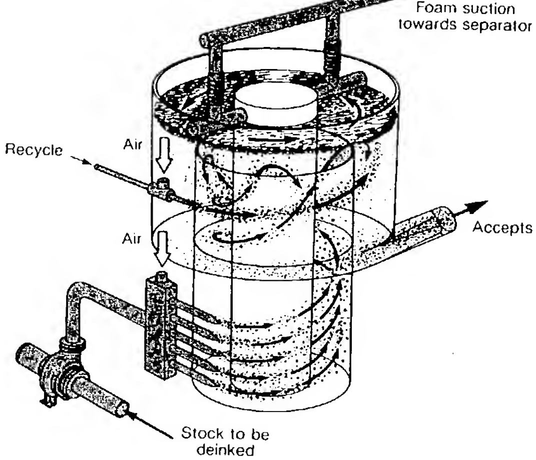

Figure 14-16. Vertical flotation cell (Lodding, Div. of Thermo Electron).

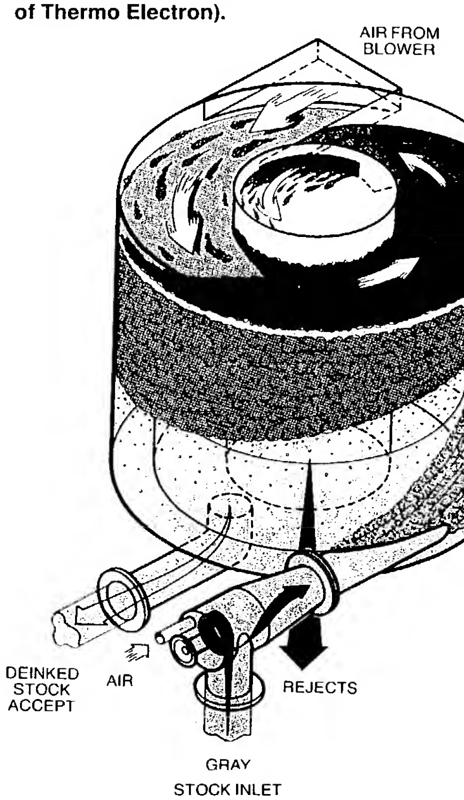

Figure 14-17. Swemac Hellberg flotation cell.

Combined Washing and Flotation

Since the washing and flotation methods have respective advantages, the notion of utilizing a hybrid process is attractive. However, the principles involved and the chemicals utilized have been quite different, and this lack of compatibility has been a stumbling block. The objective in washing is to break the ink down into particles under 15 microns, render them hydrophillic, and keep them finely dispersed. For effective flotation removal, the ink particles must form hydrophobic flocs, ideally in the size range from 30 to 60 microns.

The problem of process incompatibility has been overcome by the development of a new class of surfactant called a "displector" (coined from dispersant and collector). These chemicals provide enough hydrophillicity for the ink particles to remain dispersed during washing operations, while retaining enough adhesion between ink particles and air bubbles for flotation to be effective (6).

For maximum operating flexibility and improved secondary fiber quality, a modern combined or hybrid system utilizing both washing and flotation technology is now the preferred choice. A representative combined system is depicted schematically in figure 14-18. In this two-stage system, washing serves to remove fines and fillers along with the smaller ink particles. Washing also appears to enhance the subsequent flotation stage by removing some contaminant elements from the furnish which inhibit attachment of ink particles to bubbles. The subsequent flotation step is then effective in handling the more difficult-to-disperse inks while also removing other lightweight contaminants. It must be noted that, depending on system objectives, some hybrid process designers prefer to carry out flotation first followed by washing.

14.6 SECONDARY FIBER UTILIZATION

Secondary fibers have distinctly different characteristics when compared to virgin pulps. Therefore, papermakers should consider each secondary pulp as a distinct furnish component with separate targets for cleanliness, freeness, degree of refining, etc.

Regardless of how they have been processed, secondary pulps always contain some residual contamination that will have an impact on papermachine operation. Waxes, glues, inks, and a variety of dissolved solids tend to build up in the system and precipitate or agglomerate at various points along the papermachine. For example, stickies and hot melts are prone to precipitate on fabrics and

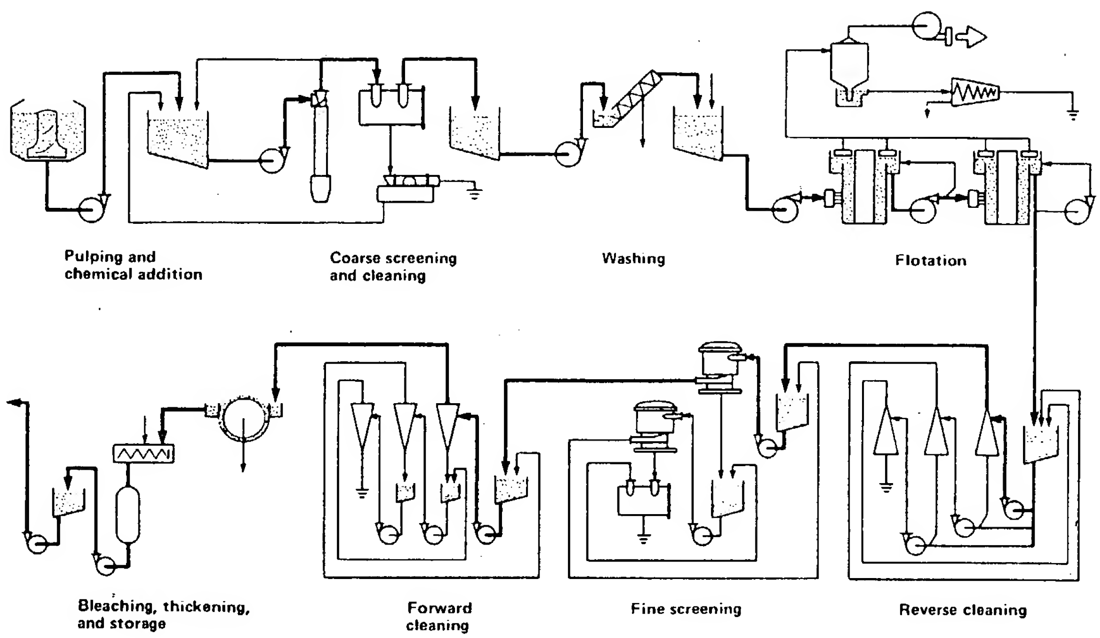

FIGURE 14-18. Combined washing and flotation deinking system (Lodding, Div. of Thermo Electron)

dryer surfaces. Ink and clay may agglomerate into larger particles in the white water system and ultimately end up as visible dirt in the paper product. Mills that convert to a partial secondary pulp furnish find that a more stringent program of fabric cleaning and/or system boilout is required.

Generally, pressrooms have found that recycled newsprint and other printing papers that contain secondary fiber are not significantly different with respect to runnability. Differences in printability and appearance are more apparent. Recycled sheets tend to be more absorbent because of higher sheet porosity; therefore, more ink is required in printing which causes poorer printing resolution and higher rub-off. However, the biggest concern for white grades is appearance. Ink spots and other dirt specks often cannot be tolerated, and brightness may be significantly lower. Secondary fiber usually cannot be used as a furnish component in the most critical grades.

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